Enclosed farmland

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Chapter 7:
Enclosed Farmland

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Key Findings*

Enclosed Farmland is a vital habitat in the UK in terms of food production and the provision of landscape, recreation and other cultural benefits[1]. However, it also imposes important negative effects on the UK, including greenhouse gas emissions, diffuse water pollution and losses to biodiversity[1]. The challenge for the future will be to enhance the multiple ecosystem services that Enclosed Farmland provides despite a rapidly changing environment.

[1] *well established*

Enclosed Farmland is managed largely for food production. Changes in this habitat are driven mainly by changes in technologies, markets and policies. Climate change[a] and greater cultivation of bioenergy crops[c] are likely to become important drivers in the future[c]. Arable and Horticultural land occupies an estimated 19% of the UK land area (concentrated in eastern England) and Improved Grassland a further 21% (concentrated in the wetter, western parts of the UK)[1]. The 20th Century saw a trend for specialisation and landscape homogenisation, which was driven by mechanisation, markets and policies, among other factors[1]. The area of enclosed grassland increased by 5.4% between 1998 and 2007, due to agri-environment and former set-aside schemes, which restored some landscape diversity[1]. The length of hedgerows in Great Britain fell from an estimated 624,000 km in 1984 to 506,000 km by 1990[1]. This loss was caused more by poor management than by outright removal, and was largely stemmed by policy changes[a]. The area of farm woodlands in the UK increased from 280,000 ha to 700,000 ha between 1981 and 2008[1]. Pond numbers and quality have declined, especially in arable areas[a]. Climate change and increasing pressure on water supplies are expected to influence land management in the future through both mitigation and adaptation measures[a], including planting an estimated 350,000 ha of perennial bioenergy crops[c].

[1] *well established*
[a] *virtually certain*
[c] *likely*

Provisioning is the major ecosystem service provided by Enclosed Farmland, underpinning the UK agri-food sector, which contributes more than 6% of UK GDP[1]. Until the 1990s, levels of agricultural production increased greatly, causing an increase in external environmental costs and at the expense of other ecosystem services[1]. The increases in total agricultural productivity slowed during the 1990s, and hence the deterioration in other ecosystem services was reduced[b]. Production has increased since 1945, driven by new technologies and supported by deliberate policy interventions; for example, wheat yields increased from 2.5 tonnes per hectare per year (t/ha/yr) in 1940 and have stabilised at around 8 t/ha/yr since 2000[1]. The value of many UK agricultural products fell in the late 1990s, but recently rose again. Self-sufficiency in production of indigenous foods increased from 30% to 40% in the 1930s, and is now 73%[1].

[1] *well established*
[b] *very likely*

The contributions of the habitats of Enclosed Farmland to regulating services have often been negative, but are improving[2]. Levels of carbon in Arable and Horticultural soils fell between 1998 and 2007, while stocks under Improved Grassland remained steady at 61 t/ha[2]. The burden placed by agricultural inputs on regulating services, through local and exported pollution, is declining as nutrients are used more efficiently and livestock numbers fall[b]. For example, absolute values of non-carbon dioxide greenhouse gas emissions from UK agriculture have fallen by 19% since 1990, although they still accounted for 45% of the UK total in 2006[2]. Similarly, over 91% of UK ammonia emissions come from agricultural sources, and were estimated at 0.29 megatonnes (Mt) in 2007, compared to the 1990 estimate of 0.36 Mt[2]. Reductions in fertiliser use are contributing to falls in nitrate levels in rivers[a]. Pollination and biological pest control are provided by many invertebrates of Enclosed Farmland. However, numbers of honey bee colonies in England have declined by 54% since 1985[1]. Little is known of national trends in populations of biological control agents, nor of the relationships between the various organisms providing regulating services and crop yield.

[1] *well established*
[2] *established but incomplete evidence*
[a] *virtually certain*
[b] *very likely*

* Each Key Finding has been assigned a level of scientific certainty, based on a 4-box model and complemented, where possible, with a likelihood scale. Superscript numbers and letters indicate the uncertainty term assigned to each finding. Full details of each term and how they were assigned are presented in Appendix 7.1.

Millions of people enjoy the cultural benefits of Enclosed Farmland landscapes and their associated species[1]. Many Areas of Outstanding Natural Beauty and National Parks contain areas of Enclosed Farmland, and some landscapes are characterised by their patterns of crops, grass, woodlands, linear features and farm buildings[1]. The UK's farmland provides health benefits in terms of both the opportunities to exercise within it and the food produced[2]. Many species of plants, birds, invertebrates and mammals are directly associated with farmland cultural services[1], although quantitative data are lacking on their values and benefits. During the 20th Century, agriculture was associated with major declines in the diversity and numbers of plants, terrestrial invertebrates and vertebrates; for example, by 2000, the numbers of specialist farmland birds had fallen to 40% of their 1970 levels, and they have fallen a further 4% since then[1]. Only 26 out of 710 Areas/Sites of Special Scientific Interest on Enclosed Farmland are in favourable condition[1]. The UK's agricultural sector employs 470,000 people today, which is fewer than 2% of the workforce and half the number employed in 1973[1].

[1] *well established*
[2] *established but incomplete evidence*

Many interactions between provisioning and other ecosystem services are negative, partly because of releases of nutrients from agriculture as greenhouse gas emissions and diffuse pollution, and partly because of competition between crops and other habitats and taxa[2]. Better management of nutrients at crop, farm and catchment scales will improve regulating services without affecting food production[a]. However, productive agriculture involves removing weeds and pests, and simplifying landscapes, with inevitably negative consequences for biodiversity[1]. Extensive agriculture cannot meet all the UK's food production needs[3], so delivering both food and other ecosystem services requires the management of parcels of land for different purposes, from field to catchment scales[c]. Even then, it is not known whether the demand for ecosystem services can be met. Targeted regulations and guidance are being used to enhance levels of ecosystem services with some success; for example the control of diffuse water pollution[1]. Proposals to increase the area of bioenergy cropping will affect food production unless grown on poor quality farmland[a].

[1] *well established*
[2] *established but incomplete evidence*
[3] *competing explanations*
[a] *virtually certain*
[c] *likely*

Agriculture in the UK needs to: produce more food and energy; be more efficient in terms of resource utilisation; better provide ecosystem services other than production; and be resilient to climate and other changes[1]. Low-input agriculture provides higher levels of many services per unit area, but cannot meet expected requirements for food production, unless demand for food and energy is also met in other ways[1]. There is scope for increasing the productivity of food production both per unit area and per unit of resource, while the diversification of crop types and using trees or housing to create cooler conditions for livestock will help to manage the risks of climate change[b]. The volatile and complex nature of regulations and markets makes delivery of other ecosystem services difficult[1]. Values for such services are changing rapidly, and it is not clear whether agri-environment schemes are cost-effective mechanisms for delivering all ecosystem services from Enclosed Farmland[c].

[1] *well established*
[b] *very likely*
[c] *likely*

New research is needed to discover ways to enhance other ecosystem services while continuing to increase food production[1]. Some of this research should focus on traditional agricultural areas, such as breeding[1]; whereas some may be required in newer areas, such as the manipulation of biogeochemical processes through an improved understanding of soil function[c]. We need more information on how ecosystem services interact if we are to generate optimum farmed landscapes[1]. In particular, we lack information on the contribution of regulating services to food production[1]. In many cases, we only have access to proxy data, for example, declining pollinator numbers rather than the impacts of those declines on food production[1]. This is because the critical experiments are difficult and expensive to conduct at appropriate scales. It may not be possible to meet future demands for all ecosystem services[c]. Public engagement is needed to establish priorities, values and mechanisms for the delivery of ecosystem services from Enclosed Farmland, not least because the full cost of these services may prove far greater than allowed for in current policies and markets[c].

[1] *well established*
[c] *likely*

7.1 Introduction

Enclosed Farmland encompasses the cropped and grass fields that cover much of the UK's lowlands, along with the networks of hedges and ditches and the small woodlands interspersed among them. Enclosed Farmland is largely managed to produce food, using practices that result in some undesirable losses of nutrients and sediments into water, and greenhouse gases and ammonia into the atmosphere, as well as some that have caused large losses in the abundance and diversity of many species. By contrast, Enclosed Farmland is often also managed to provide positive outcomes or benefits, especially for providing landscape character, habitats for wildlife and opportunities for leisure. The management of UK Enclosed Farmland impacts on ecosystem services globally through the import and export of food, and through the use and alteration of energy and water, and emissions of greenhouse gases (Chapter 21). In this chapter we look at the ecosystem services provided by Enclosed Farmland and how they have changed in response to different drivers. This analysis helps us to consider how Enclosed Farmland might be managed sustainably in the UK in order to meet the expected global demands for more food and bioenergy, biodiversity conservation, and the enhancement of other ecosystem services.

7.1.1 Description of the Enclosed Farmland Broad Habitat

In the UK NEA, Enclosed Farmland comprises the two component habitats 'Arable and Horticultural' and 'Improved Grassland' (Jackson 2000), defined by vegetation, rather than land use (**Box 7.1**). Arable and Horticultural is identified on the basis of crops, grass leys, ploughed land and weedy vegetation characteristic of early succession set-aside. Improved Grassland occurs when palatable grasses (mainly perennial rye-grass (*Lolium perenne*), timothy (*Phleum pretense*), cock's-foot (*Dactylis glomerata*), crested dog's-tail (*Cynosurus cristatus*), and Yorkshire fog (*Holcus lanatus*)) exceed 75% cover and there is a restricted range of broadleaved species (Howard *et al.* 2003; Maskell *et al.* 2008). Hedgerows, ditches, ponds, farm woodlands and buildings interspersed among arable and grassland are also included in this chapter. The more species-rich habitats of Acid, Neutral and Calcareous Grasslands are dealt with separately within the Semi-natural Grassland chapter of the UK NEA (Chapter 6).

In 2007, Enclosed Farmland covered 39.3% of the UK's land area, with Arable and Horticultural and Improved Grassland habitats accounting for 18.8% and 20.5% of UK land cover, respectively (Carey *et al.* 2008; **Figure 7.1**). The extent of Enclosed Farmland, and the ratio of extent of Arable and Horticultural and Improved Grassland, differs between the four countries of the UK. This reflects the drier conditions in the south and east of the UK (which are more conducive to arable) and the wetter conditions in the west. Thus, divided by country:

- 52.1% of land area in England is Enclosed Farmland, consisting of 30.4% Arable and Horticultural and 21.7% Improved Grassland (Carey *et al.* 2008);
- 17.8% of land area in Scotland is Enclosed Farmland, consisting of 6.6% Arable and Horticultural and 11.2% Improved Grassland (more than 72% of the combined extent of both habitats is concentrated on the most nutrient-rich soils in the eastern lowlands of the country) (Norton *et al.* 2009a);
- 44% of land area in Northern Ireland is Enclosed Farmland, consisting of 3.5% Arable and Horticultural and 40.5% Improved Grassland (Cooper *et al.* 2009); and,
- 37.4% of land area in Wales is Enclosed Farmland, consisting of 3.4% Arable and Horticultural and 34% Improved Grassland (Carey *et al.* 2008).

Box 7.1 Data availability and interpretation.

For the UK NEA, we have used data from surveys undertaken by government, industry and research bodies over many years, usually collected with very different purposes in mind. Many of the datasets that are available refer to all agricultural land, not just to Enclosed Farmland; we have, therefore, focused on agricultural production concentrated in the lowlands, but key datasets, such as greenhouse gas emissions from livestock, also include uplands. Different datasets can use slightly different definitions for apparently similar observations. In particular, we define Enclosed Farmland by land cover, not economic use, so recreational grasslands are counted as Improved Grassland by the Countryside Survey, but excluded from agricultural statistics. Finally, while the four countries of the UK currently run separate administrations for many elements of government pertinent to the habitats and services discussed in this chapter, this has not always been the case, thus limiting the availability of reliable, UK-wide, long-term datasets on some issues.

7.1.1.1 Fields: Arable and Horticultural

Most arable land is cultivated to grow annually harvested crops. Cereals are the dominant crops sown, occupying 66.7% of the total area under crops in 2009 (Defra 2009a; Chapter 15). Wheat and barley alone now account for almost 95% of the total cereal area. Wheat grows well on heavier soils, but less well in areas of high rainfall. It is grown mainly for animal feed and milling. Barley can tolerate greater rainfall, but prefers lighter soils. Oats can tolerate more acidic soils, and so, traditionally, have been grown in Scotland, Wales and north-western England. Rape provides culinary and industrial oils, feedstock for biodiesel, livestock feed, and provides a break in cereal rotations for improved control of weeds and crop diseases. A wide variety of other crops are grown, usually for food or animal fodder, seldom occupying more than 10% of the agricultural area in a given county or region. These crops include sugar beet, forage brassicas, field beans, peas and forage maize. Potatoes grow best in deep, well-drained and stone-free soils, so are mostly grown on the silt and peat soils of eastern England, Shropshire, Cheshire, Fife and Angus. In Northern Ireland, only 17% of farms have arable or horticultural crops. Barley (26,700 hectares; ha) is the main crop grown, followed by wheat (10,100 ha) (DARD 2010). Only 43,000 ha of Welsh arable land is occupied by cereals, potatoes and horticulture, along with some oilseeds (3,000 ha) and livestock feeds, such as maize (19,000 ha); while 95,000 ha is sown to improved grasslands which are less than five years old.

A small, but growing, amount of land is used to grow crops for other uses, particularly in England. These include flax and hemp for fibre, as well as high market value crops grown for

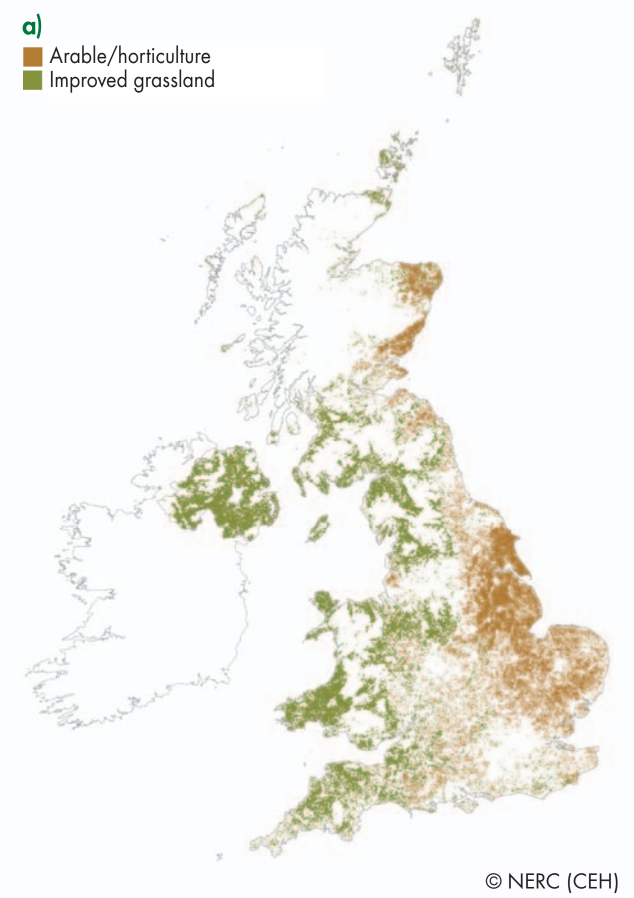

Figure 7.1 Distribution of UK NEA Enclosed Farmland habitat in the UK a) Dominant (>51% area per 1 km cell) Enclosed Farmland type and b) percentage cover per 1 km cell.

pharmaceutical and medicinal extracts, essential oils, dyes, flavours, fragrances, cosmetics and nutritional supplements. Examples of speciality crops include borage and viper's-bugloss, which are grown for their oil; and dill, foxglove and chamomile which are grown for high-value medicinal or herbal extracts. Arable land has also included early successional set-aside (voluntary from 1987 and compulsory since 1992): over 180,000 ha was set-aside in 2007/08, the last year before the policy was discontinued.

At present, production horticulture accounts for 3% of the UK's agricultural area (The Smith Institute 2009). Orchards are concentrated in Kent, Herefordshire and Worcestershire; soft fruit production is very widespread, but the production of raspberries in Fife is worthy of note; vegetable-growing is largely found between Humberside and Essex; and flowers are mainly produced in Lincolnshire, Cornwall and the Isles of Scilly.

7.1.1.2 Fields: Improved Grassland

Most Improved Grassland is managed to provide food for livestock, mainly sheep and beef and dairy cattle. It is typically in the form of 'improved' pasture or long-term leys, managed using herbicides, fertilisers, ploughing, reseeding, liming and drainage to favour competitive, nitrogen-responsive grasses which provide silage to feed livestock over the winter and grazing for the rest of the year (Fuller 1987). There is a continuum from high-input, monoculture swards to low-input, botanically diverse Semi-natural Grassland (treated as a separate UK NEA Broad Habitat). Improved Grassland is concentrated in Wales, western and northern Scotland, Northern Ireland, northern England and south-west England. These places are less suitable for arable crops because of their topography, high rainfall and more acidic soils.

7.1.1.3 Fields: biomass crops

Biomass crops are perennial crops that remain in the ground for successive harvests, potentially for more than 25 years. The two most common biomass crops in the UK are short rotation coppice (SRC), mainly willow (*Salix* species), and *Miscanthus* x *giganteus*, a dense, tall, perennial rhizomatous grass. These crops currently occupy only about 15,500 ha (Booth *et al.* 2009).

7.1.1.4 Farm woodland

Farm woodlands are typically small patches of woodland embedded within an agricultural landscape. There is no agreed definition of 'farm woodland', but it is generally accepted that 0.25 ha is a reasonable minimum area (FCS 2007). The most recent survey found more than 250,000 woodlands with areas from 0.1–2 ha in Great Britain (GB) (Forestry Commission 2003), many of which would have been in Enclosed Farmland. Such woodlands can be high forest, coppice or scrub, with variable amounts of open space (Evans 1984). Small woodlands are predominantly broadleaved (most frequently oak (*Quercus* species) and ash (*Fraxinus excelsior*), especially in England and Wales. Spruce species (*Picea* species) are the most common conifers.

7.1.1.5 Field boundaries and ponds

Hedgerows, stone walls, dykes, fences and earth banks are all common field boundary features across the UK, originally created to enhance agricultural production, notably by stock proofing. Hedgerows usually consist of a linear strip of low, woody vegetation, sometimes punctuated by standard trees and often associated with other boundary features such as banks, ditches and uncultivated field margins. The planting of many of the UK's hedgerows was triggered by the Enclosure Acts of the 18th Century and before, creating a landscape with a social and historical dimension that is unusual on Earth (Rackham 1986). Hedgerows are concentrated in southern England and Wales, and are relatively scarce in Scotland. Northern Ireland has the UK's highest density of field boundaries, with 118,000 km of hedges in 1998 (Cooper & McCann 2000).

7.1.1.6 Buildings and gardens

Farm buildings, yards, houses, gardens and green lanes are not included in the definition of Enclosed Farmland, but play a major part in landscape character and hence the cultural services from farmland. They also provide habitat for barn swallows (*Hirundo rustica*), bats and other species. We are not aware of national data on the numbers, distribution and types of these features.

7.1.1.7 Enclosed Farmland landscapes

Enclosed Farmland has evolved in response to interactions between cultural, economic, technological and environmental factors, giving rise to distinctive yet dynamic landscapes of fields, buildings, linear and point features, woodlands and other habitats. These landscapes have been classified by country into Landscape Character Areas (they are termed National Character Areas in England). Historically, they have been considerably influenced by the development of agricultural systems, especially the 'planned countryside' associated with the Enclosure Acts of the 18th Century and the contrasting 'ancient countryside' which reflects a longer history of gradual evolution (Rackham 1986). Today, large, tilled fields dominate the farmed landscape in southern England, with scattered woodland patches and farm buildings. Further north and west in England, fields are smaller and less regular in shape, with more hedgerow trees and pasture. Pasture dominates even more in Wales and Northern Ireland, but tilled fields once again prevail in parts of the east and south-east of Scotland.

Crofting is a unique land use system, important socially and culturally, and often accompanied by a rich and varied fauna and flora (SNH 2009). It is associated with distinctive, small-scale cropping patterns, and is dominated by mixed farming; fields are lined with stone dykes and sparse stands of gorse instead of stock-proof hedges (Wilson *et al*. 2009). Crofting covers nearly 10% of Scottish farmland, mostly in the north-west; there are currently around 10,000–12,000 crofters on nearly 18,000 crofts (Slee *et al.* 2009).

7.1.2 Interactions Between Enclosed Farmland and Other UK NEA Broad Habitats

The major direct interactions Enclosed Farmland has with other UK habitats are in terms of exchanges of land into and out of agriculture through land use change and through agricultural management that cuts across Broad Habitat boundaries (especially in the uplands). Imports and exports of water, energy, nutrients and pollutants are dealt with in Section 7.3.

The greatest net transfer of land into and out of Enclosed Farmland in recent decades has been the large-scale conversion from Semi-natural Grassland (Chapter 6) to more intensive agriculture during the mid-20th Century. Fuller (1987) reported that, between 1930 and 1984, 97% of grasslands in England and Wales had been improved. In recent decades, this conversion has slowed, with large fields close to more intensive grassland the most likely to change (Petit & Firbank 2006). Flows between habitats other than Neutral Grassland were negligible between 1998 and 2007 (Carey *et al.* 2008). While there remains pressure to convert Enclosed Farmland into built land, the actual proportion of new dwellings built on agricultural land has fallen from around 28% during the 1990s to less than 15% since 2005 (FLUFP 2010).

Upland farming in the north and west of Britain is dominated by the extensive rearing of cattle and sheep. The Enclosed Farmland areas on such farms may be relatively small, but their management dictates the intensity of grazing across the farm as a whole, and hence on the semi-natural vegetation used as grazing land (permanent grassland, moorland and bog, rush pasture and marsh, Machair and Sand Dunes). The intensification of grassland and cropping management practices in enclosed areas has allowed an overall increase in the livestock carrying capacity of these areas, resulting in overgrazing of many upland habitats (Samsom 1999). Changes in support payments as a result of the reform of the Common Agricultural Policy (CAP) are now driving stocking densities back down and raising the prospect of under-grazing in some parts of the uplands (Scottish Agricultural College 2008).

7.2 Trends and Changes in Enclosed Farmland

This section looks at the change in extent and status of Enclosed Farmland habitats and the main causes of these changes.

7.2.1 Changes in Extent and Status

7.2.1.1 Fields

According to official agricultural statistics for England, the total area for arable and permanent grass (excluding rough grazing, but including Semi-natural Grassland) fell during the 20th Century, with some substitution of grass by cereals (**Figure 7.2**). The GB area of Arable and Horticultural

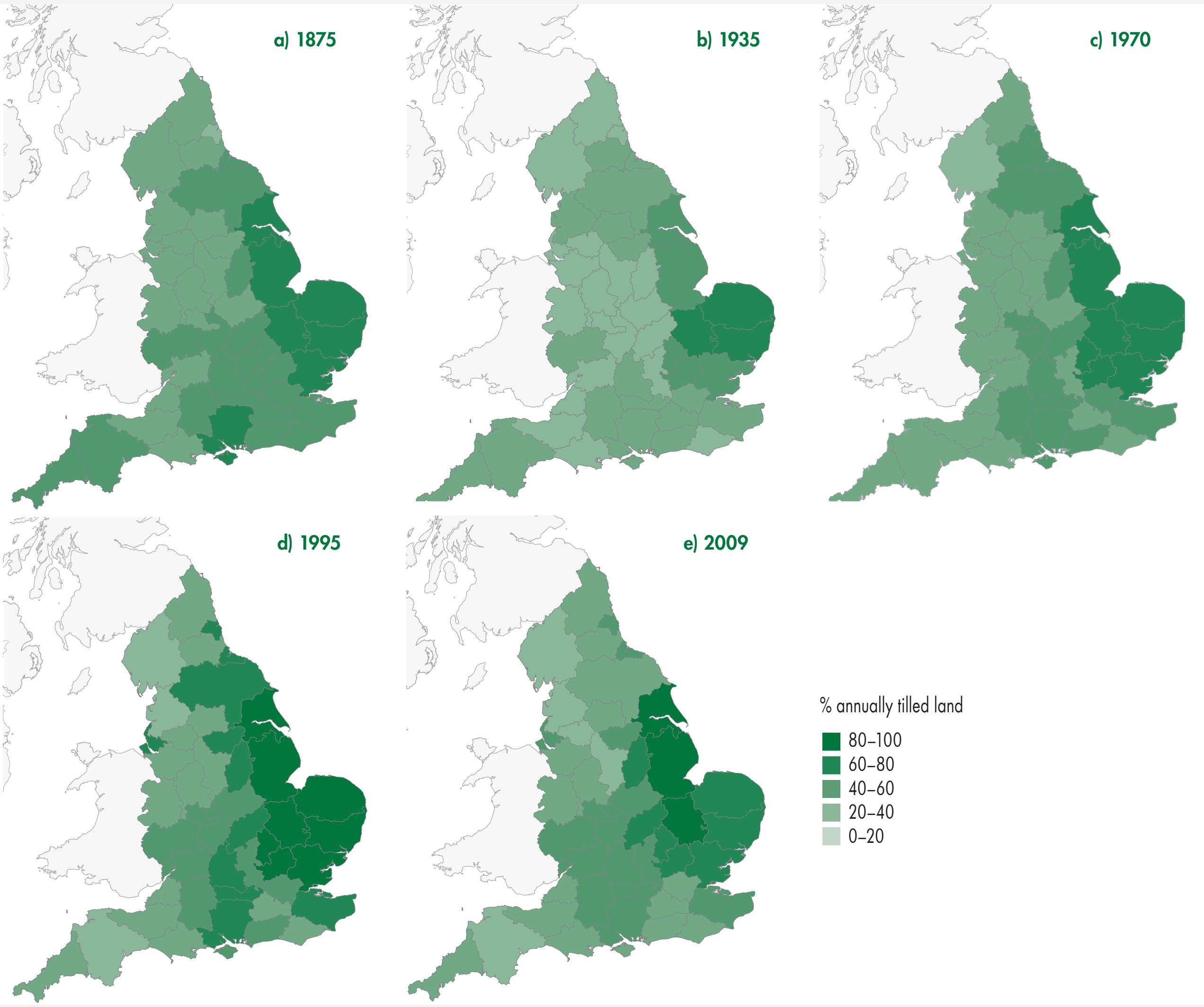

Figure 7.2 The amount of annually tilled land in England, as a percentage of total farmed area by county in a) 1875, b) 1935, c) 1970, d) 1995 and e) 2009, based on agricultural census returns. Source: adapted and updated from Robinson & Sutherland (2002).

land fell from 5.3 million ha in 1984 to 4.1 million ha in 2007, while the area of Improved Grassland also fell from 5.9 million ha to 4.5 million ha over the same time period (note: these latter changes were concentrated in England). The major transfers were to Neutral Grassland, reflecting less intensive management; the extent to which this was due to agri-environment schemes, as opposed to neglect, is not known (Carey *et al.* 2008). Note that Countryside Survey data conflicts with evidence from agricultural statistics in ways that could be accounted for by the conversion of some agricultural land to woodland (Bibby 2009).

Maize and oilseed rape have increased dramatically in area in recent decades, while areas of turnips, swedes and fodder rape have declined. Changes in dominance of different cereals are illustrated by the situation in Scotland where, from the mid-1940s to mid-1950s, about 80% of the area planted was to oats, 15% to barley and the rest to wheat. By around 1980, oats had declined to less than 10% of the area planted, while barley area increased to about 80–85%. Since then, wheat has increased to about 25% of area planted, at the expense of barley (Miller *et al.* 2009). The area of orchards rose steadily until the 1950s, but has since been in decline (**Figure 7.3**). Further details of inter-country variation in changes in extent of different crops are given in Chapter 15.

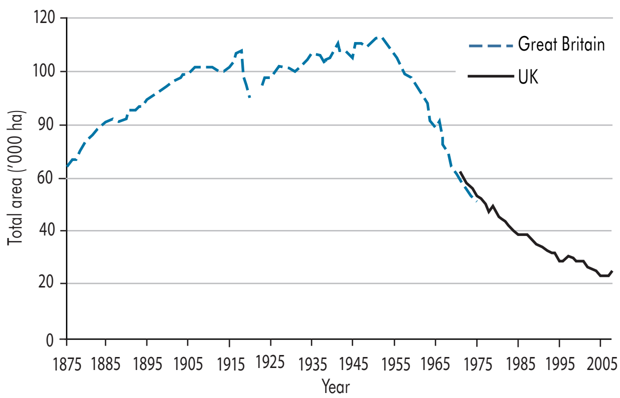

Figure 7.3 Long-term trends in areas of orchards (in thousands of ha) in GB followed by UK. Source: reproduced from Keep (2009). © Crown copyright.

Figure 7.4 Trends in livestock numbers. Total sheep and lambs, cattle and calves, and pigs for a) England, b) Scotland, c) Wales from 1940 to 2009 and for d) Northern Ireland from 1990 to 2009. These data do not distinguish between livestock in enclosed and unenclosed farming habitats. Source: June census data from Defra, Department of Agriculture and Rural Development, Scottish Government and Welsh Assembly Government; data available from http://www.defra.gov.uk/statistics/foodfarm/landuselivestock/junesurvey/.

Historically, most young grasslands were grass-clover mixes, in rotation with arable crops, to restore fertility and provide hay. During the course of the 20th Century, these have been replaced by regularly reseeded long-term leys, designed to maximise production of grazing or silage (Chapter 15). The resulting forage is fed to stock over the winter, along with concentrates and sometimes forage crops. Livestock numbers rose from the mid-20th Century to the 1990s, sustained by increasing inputs of inorganic fertilisers and feed; since then, they have fallen (**Figure 7.4**; Chapter 15). Stocking densities have increased because of the tendency to concentrate the remaining livestock on the more productive, enclosed areas of grazing on farms.

Turnover between arable crop types and grassland has been extensive and complex, has occurred at scales from national to rotations on individual farms, and has been happening for decades (Haines-Young *et al.* 2003; Swetnam 2007; **Table 7.1**). For instance, there was a 14.5% decrease in area of Arable and Horticultural broad habitat in Northern Ireland between 1998 and 2007 (Cooper *et al.* 2009), including a 32% decrease in the area of land in potatoes (DARD 2010). In Scotland, there was a 14% decrease in the extent of Arable and Horticultural broad habitat between 1998 and 2007 (in contrast to the relative stability seen between 1990 and 1998), but there was a significant increase (9%) in the extent of Improved Grassland (Norton *et al.* 2009a).

The area of agricultural land under bioenergy crops is increasing in the UK, but from a very low baseline (Lovett *et al.* 2009; Chapter 15). By 2007, the area of *Miscanthus* was 12,600 ha and SRC 2,600 ha in England. In Scotland, the area planted with bioenergy crops, or approved for planting up until the end of 2006, was 300 ha, with applications for planting in 2007 and 2008 amounting to around 600 ha. In Northern Ireland, 800 ha of SRC have been planted or approved for planting, while in Wales there is only known to be 40 ha of SRC and 72 ha of *Miscanthus* (Sherrington & Moran 2010).

7.2.1.2 Hedgerows

The original agricultural functions of linear features have often been lost, not least due to declines in stock numbers in now arable-dominated areas. Yet hedgerows remain important for the habitats they provide, the connections they make between habitats, for their role in reducing diffuse pollution, and for their contribution to the cultural landscape (Barr & Petit 2001; Ballantine *et al.* 2009). The first national data on hedgerows were collected in 1984 (Barr & Gillespie 2000), before which it is believed that many hedgerows were removed as fields were enlarged to facilitate the use of tractors and other machinery. Between 1951 and 2007, the number of hedgerow trees fell dramatically across Britain from over 56 million to less than 2 million (Carey *et al.* 2008); around half of these were elm trees killed by Dutch Elm Disease (Forest Research 2010). The estimated length of 624,000 km of 'managed' hedge in GB recorded in 1984 decreased to 506,000 km by 1990 (Petit *et al.* 2003). Subsequent protection (e.g. under the Hedgerow Regulations in England and Wales) has severely restricted the removal of hedgerows and much reduced the rate of subsequent losses (**Figure 7.5**), which were often the result of poor management rather than outright removal (Smart *et al.* 2009). Under half (48%) of managed hedges in GB were classified as being in good structural condition in 2007 (Carey *et al.* 2008).

We are unaware of published data on national trends in ditches and their status.

7.2.1.3 Farm woodland

Farm woodlands have been planted with a variety of intentions, including providing productive alternative land uses to agriculture, shelter for stock, and improving biodiversity, landscape and recreation (John Clegg *et al.* 2002). According to the Forestry Commission, between 1981 and 2008, the area of land recorded as farm woodland increased from about 280,000 ha to 700,000 ha (Forestry Commission 2009), with 45% being in England, a similar amount in Scotland, 8% in Wales and the remainder in Northern Ireland (**Figure 7.6**).

Throughout the 20th Century, game-shooting has been one of the main reasons for the planting of farm woodlands (Duckworth *et al.* 2003). Pheasant (*Phasianus colchicus*) shooting is a major recreational activity that is normally dependent on a matrix of farmland and woodland habitats, and an estimated 830,000 ha of UK woodland is being managed primarily for this sport (PACEC 2006). Management of woodlands for game species contributes directly to the conservation of birds and other wildlife (Draycott *et al.* 2008).

Farm woodlands are rarely planted primarily for timber and fuel; they are often isolated from other woodlands and have poor access, which makes management and extraction of harvested material difficult. However, some are now being better managed, and the recent widespread adoption of wood fuel boilers on farms and larger premises has encouraged the production of woodchip from a wide range of woodland types.

Table 7.1 Changes in areas of Improved Grassland and Arable and Horticultural habitats across England, Scotland and Wales since 1990 showing statistical significance of changes between adjacent times (*p < 0.05; **p< 0.01). Data collected using field sampling rather than agricultural census returns. All values are thousands of hectares (ha). Source: reproduced from Keep (2009). ©Crown copyright. Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

		Arable & Horticulture			Improved Grassland		
		'000 ha					
		1990	1998	2007	1990	1998	2007
England	Easterly lowlands	3,191	3,127	2,907 **	928	926	1,056 *
	Westerly lowlands	1,147	1,223 *	1,061 **	1,809	1,537 **	1,576
	Uplands	41	39	34	284	250	225
Scotland	Lowlands	511	519	462	539	526	580
	Intermediate uplands and islands	75	95 *	71	214	245	267
	True uplands	7	4	2	62	60	60
Wales	Lowlands	46	55	63	501	457 *	467
	Uplands	6	6	10 **	228	249 **	263

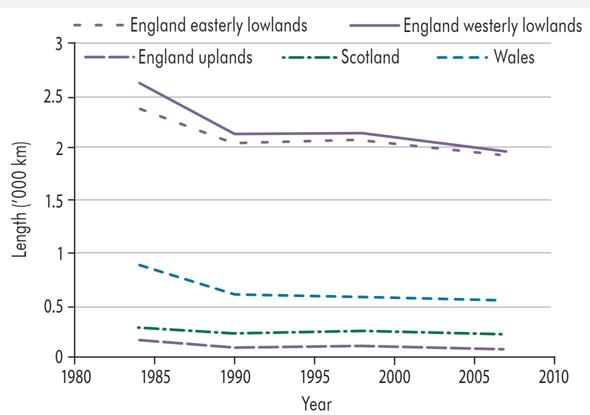

Figure 7.5 Trends in the overall length (thousands of km) of managed hedgerows. Source: data from Countryside Survey (Carey *et al.* 2008). Countryside Survey data owned by NERC – Centre for Ecology & Hydrology.

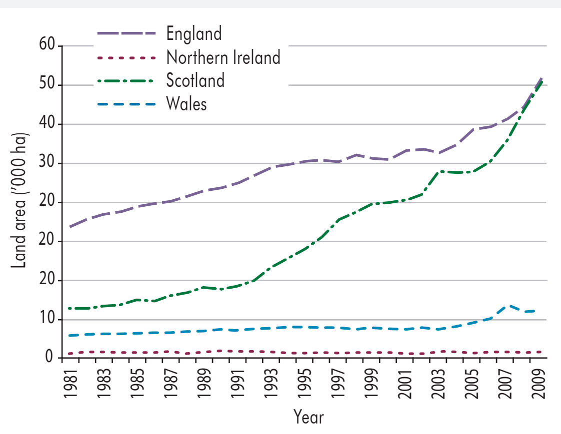

Figure 7.6 Trends in the overall land area (thousands of hectares) covered by farm woodlands from 1981 to 2009. Source: data from Forestry Commission (2009).

7.2.1.4 Ponds

In the late 19th Century, the number of ponds in England and Wales is estimated to have been about 800,000 (Rackham 1986). Many ponds were lost, however, largely due to the drainage of the land and the infilling of ponds that had become redundant as livestock watering sites or hindered large-scale agricultural operations. Numbers fell to an estimated 200,000 in the 1980s, but are now recovering; an estimated 478,000 ponds existed across GB in 2007 (Williams *et al.* 2010). Over the same period, the invertebrate species richness of lowland ponds declined by 20%, and the proportion of ponds in 'poor' or 'very poor' condition increased by 17% (Williams *et al.* 2010). Causes of this ecological degradation include elevated nitrate concentrations, runoff from roads, increased tree shading and the transport of sediment through stream inflows.

7.2.2 Drivers of Change in Enclosed Farmland Habitats

Management of Enclosed Farmland results from the decisions of individual land managers in the light of markets, policies, the characteristics of the land, environmental conditions, available knowledge and technology, and the attitudes and objectives of the land managers themselves (McIntyre *et al.* 2009; Chapter 15). This means that the extent and vegetation of this habitat, and the ecosystem services provided, may change very rapidly. A summary of the drivers of change in the extent and status of Enclosed Farmland habitats, and their relative importance, is shown in **Table 7.2**.

7.2.2.1 Climate change (temperature/precipitation) and sea-level rise

During the 20th Century, the UK's climate was stable enough not to drive major changes in the extent and management of Enclosed Farmland. That situation is changing rapidly as agriculture must increasingly adapt to climate change and meet political expectations to reduce greenhouse gas emissions, sequester carbon and produce bioenergy. Here, we address adaptation options directly related to the management of Enclosed Farmland, and not the rest of the food chain. Options for mitigating greenhouse gas emissions and the potential indirect impacts of climate change on Enclosed Farmland resulting from reduced agricultural productivity in other parts of the world are addressed in Section 7.3.2.1.

Adaptation to climate change. There is the potential for an increase in the productivity of UK agriculture due to climate change (Parry *et al.* 2008). The UK's climate is expected to become warmer (Jenkins *et al.* 2009), and expected increases in atmospheric carbon dioxide are likely to have a fertilising effect on plant growth (Long *et al.* 2004), but with a potential cost of reduced plant protein content (DaMatta *et al.* 2010; Cotrufo *et al.* 1998).

However, patterns of rainfall are expected to change, with wetter winters in the grassland-dominated north and west, and drier summers in the south-east, as well as more extreme weather events overall (Jenkins *et al.* 2009). Arable farming may be compromised by droughts in summer and waterlogging in winter, preventing timely agricultural operations. While agriculture currently accounts for only 2% of water abstracted in the UK, this is mostly used in the summer in the south and east of England (Defra 2010a), a time and place of peak demand. Climate change could increase this need, placing additional strain on water supplies that are already stretched.

Warmer winters facilitate the use of outdoor livestock systems, but extremes of weather threaten the resilience of livestock management, for example, if the land is too wet or hot for cattle to be put out to graze without compromising their welfare (Pilgrim *et al.* 2010). Such risks can be controlled using fully housed systems to protect livestock from heat stress in the summer; there is also scope for using more trees in grazing areas to provide cooler conditions outdoors. All year-round housing can have mixed environmental outcomes: compared with systems more reliant on grazing, housing livestock should result in reduced losses of nitrous oxide and nitrates (Pilgrim *et al.* 2010); by contrast, there is the potential for ammonia emissions to be increased (Chadwick *et al.* 2008).

Responses by farmers are likely to include more use of on-farm reservoirs and alternative crops and varieties more suited to the new climates. Italian ryegrass, for instance, could be used for summer grazing as it is drought-tolerant (Bartholomew & Williams 2009). The benefits of using this crop may include reduced nitrogen excretion, nitrous oxide emissions and enteric methane emissions by livestock, as well as reduced nitrates leaching from soils.

Sea-level rise. Sea-level rise has not been a driver of Enclosed Farmland management in the past, and while there is potential for inundation of low-lying agricultural land at some point in the future, it is not anticipated in the coming decades. Nor is a major increase in storm surges anticipated (Jenkins *et al.* 2009). However, some coastal areas may be lost to coastal realignment as part of a national response to cope with flooding in the future (FPFCD, undated).

7.2.2.2 Habitat change

Most changes in cover and management of Enclosed Farmland have been the indirect result of other social, economic and policy drivers, which are described separately. In recent years, however, there is renewed interest by national governments in developing policies for rural land use. In Scotland, A Forward Strategy for Scottish Agriculture was developed in 2001 (Scottish Executive 2001) and A Forward Strategy for Scottish Agriculture: Next Steps was produced in 2006 (Scottish Executive 2006). The Scottish Government is currently in the process of developing their land use strategy: Getting the Best From Our Land (Scottish Government 2010). In 2009, the Welsh Assembly Government produced their strategy: Farming, Food and Countryside: Building a Secure Future. A New Strategy for Farming (WAG 2009). Land use policy is evolving rapidly in England too. As recently as 2006, a major report on land use planning did not mention agriculture in its primary recommendations, which mainly addressed streamlining the English planning system to promote economic growth in other sectors (Barker 2006). However, the spike in food prices in 2008 raised the issue of food security, which has since been addressed in several key strategies (HM Government 2010; Defra 2010c).

The Foresight Land Use Futures final report (2010) highlighted the importance of both agricultural production and other ecosystem services from agricultural land, and promotes a more integrative, holistic view of land planning. This report recognises some of the major challenges currently facing land use policy in the UK, namely: increasing competition for land in the south-east of England, where much arable farming is concentrated; climate change, and the need to reduce greenhouse gas emissions and set appropriate mechanisms to value carbon; and the delivery of public goods and services from private land.

7.2.2.3 Species introduction and/or removal

Crop species have been introduced into the UK over the centuries—a process likely to be given new impetus as crops change their geographic range of suitability because of climate change. Indeed, some UK farms are already introducing melons, kiwi fruit, olives and even tea (The Times, 9 August 2010). However, climate change will also influence the spectrum of crop and livestock diseases, weeds and pests (Iglesias *et al*. 2007; Pilgrim *et al*. 2010). For example, the cattle disease Bluetongue was considered a minor threat in the UK until its appearance in northern Europe in 2006; previously, its midge vectors (*Culicoides* species) had been restricted further south, but warmer summers enabled it to spread north (Szmaragd *et al*. 2010).

There are several other mechanisms of species introductions (Davies 2007). The muntjac deer (*Muntiacus reevesi*) was deliberately introduced into the UK in the early 20th Century, and now degrades the flora of farm woodlands and impacts on the fertility of native roe deer (*Capreolus capreolus*) (Dolman & Waber 2008). The New Zealand flatworm (*Arthurdendyus triangulates*), which predates on native earthworms (*Lumbricidae*), has been introduced via garden centres (Cannon 1999) and is now spreading with unknown effects on soil function. Attempts to eradicate species have been largely restricted to economic diseases of livestock, although certain other species are notifiable and should be removed if seen (for example, the Colorado beetle (*Leptinotarsa decemlineata*), which is an invasive pest of potatoes, and ragwort (*Senecio jacobea*), which is poisonous to livestock). The outbreak of Bluetongue Virus in 2006 was controlled by vaccination (Szmaragd *et al.* 2010), and had little impact on other species or on ecosystem services.

By contrast, the eradication of the virus that caused the massive outbreak of Foot and Mouth Disease (FMD) in the UK's sheep flock in 2001 involved closing access to large areas of land valued for leisure (Phillipson *et al*. 2002). The costs to agriculture and the food chain of controlling the outbreak were estimated at around £3.1 billion (or 20% of total farming income in 2001). There were also losses to tourist businesses of a similar amount, although much of these were displaced to other businesses within the UK. The net cost of controlling the outbreak was around 0.2% of Gross Domestic Product (GDP) (Thompson *et al*. 2002). Current plans for controlling an FMD outbreak involve closing only those footpaths within 3 km of infected premises.

The UK Government has recently consulted over whether to allow the culling of badgers (*Meles meles*) as part of a package to control Bovine Tuberculosis (bTB) (Defra 2010c). In 2009, control of this disease involved slaughtering over 25,000 cattle, which cost £63 million in England alone and caused trauma to many farming households. Badger control is being considered as populations often harbour bTB, and it is proposed that their presence makes the elimination of the disease more difficult, if not impossible. Such control would impact on the cultural value of Enclosed Farmland, as the badger is a legally protected, iconic species, with societies dedicated to its conservation. The proposal is highly contentious and has been characterised as being political, rather than evidence-based (Monbiot 2010; Kendall 2010).

For a more detailed discussion of disease and pest regulation, see Chapter 14.

Table 7.2 Major drivers of change in Enclosed Farmland habitats. ⦿ denotes high agreement with much evidence and ⊙ denotes high agreement with limited evidence.

Driver	Relevant to farmland now and in future	Major driver on farmland	Evidence base
Climate change (temperature/precipitation)	✓ and increasing	Mitigation and adaptation	⦿
Climate change (sea level)	✗ but increasing	Some land loss in UK, loss of global agricultural land	⦿
Habitat change	✓	Especially interchange between grass and arable, and between crops	⦿
Species introduction and/or removal	✓	Potential for new crops, control of new pathogens, pest control	⦿
Pollution (nutrients etc.)	✓	Fertiliser and pesticides have resulted in pollution, likely to reduce as inputs lessen	⦿
Overexploitation (harvest / resource use)	✓	Responds to other drivers	⦿
Demography—population growth	Expected to be a future driver	Increasing population growth and consumption increase demand for agricultural production	⊙
Demography—demographic change	✓	Impacts on patterns of labour and management	⊙
Demography—ethnicity	✗		⊙
Demography—migration	✓	Impacts on patterns of labour and management	⊙

7.2.2.4 Pollution (nutrients, agrochemicals)

The advent of inorganic fertilisers in the early 1900s reduced the need for livestock manures and nitrogen-fixing legumes in farming systems and enabled the switch from hay to faster-growing silage, along with the cultivation of taller and denser cereal swards. It is estimated that 40–50% of the world's food is now produced using nitrogen fertiliser (Smil 2002; IFA 2009).

Over the past 25 years, there has been an ongoing decline in inorganic fertiliser applications. In 2008, the total amount of phosphate fertiliser used in GB was only 43% of that used in 1984 (Defra 2010a). While the application rate for synthetic nitrogen on arable land has remained fairly constant at around 140–150 kg/ha, the synthetic nitrogen application rate on grassland fell from 129 to 55 kg/ha (57%) between 1990 and 2008 (CCC 2010). This has coincided with reduced livestock numbers as a result of CAP reform, and, as such, may be attributable to reduced stocking densities more than improved efficiency in fertiliser use. Other factors that are likely to influence fertiliser use include rising prices (they climbed from £100/tonne (t) to more than £400/t between 1998 and 2009, and are likely to increase further given the high energy costs of producing nitrate fertiliser and the potential reduction in supplies of phosphates), and the regulations controlling diffuse water pollution (e.g. Nitrate Vulnerable Zones, the Nitrates Action Programme and the England Catchment Sensitive Farming Initiative).

Since the 1970s, the use of pesticides has been driven by the policy context. When price support was fixed to tonnage payments, prophylactic, often excessive, spraying regimes dominated. Since the 1992 switch to area-based payments, farmers have tended to adopt more targeted applications based on pest infestation thresholds, so the application rates of pesticide active ingredients per unit area have fallen (CSL data, http://pussstats.csl.gov.uk). The new EU Thematic Strategy for Pesticides is likely to reduce pesticide use on farmland even further. Pesticide use is now influenced by the industry-led Voluntary Initiative (VI), such that 85% of the sprayed area in England and Wales is now being treated with tested machines under the National Sprayer Testing Scheme and more than 2 million ha are now covered by a VI Crop Protection Management Plan (www.voluntaryinitiative.org.uk).

The spectrum of pesticides and herbicides has changed in response to technologies and policies. For example, the non-selective herbicide atrazine was used for pre-emergence weed control until its recent withdrawal because of concerns over groundwater contamination. Another non-selective herbicide, glyphosate, was widely used to control weeds and self-seeded crop plants (volunteers) on fallow land under the set-aside scheme. More recently, Genetically Modified (GM) crops have been developed to be tolerant to such herbicides, facilitating weed management (Champion *et al*. 2003), although they are not grown commercially in the UK (see Section 7.2.2.8).

Pesticides are used to enhance crop yield by controlling unwanted plants that compete with the crop, animals that feed on the crop, disease vectors and fungal infections. While modern pesticides tend to be more environmentally benign in terms of unwanted effects than the ones they replaced (Lutman & Marsh 2009), these deliberate removals have important indirect impacts on other species, discussed in Section 7.3.5.

7.2.2.5 Overexploitation (harvest and/or resource use)

The intensity of production (yields, stocking rates, etc.) is the result of more external drivers, namely markets, technologies and policies, dealt with seperately.

7.2.2.6 Demography (population growth, demographic change, ethnicity and migration)

There is little evidence of demography driving changes in UK Enclosed Farmland in recent decades, and, at a global level, agricultural production has kept pace with consumer demand. However, concerns are rising that a combination of increasing global population (to an estimated 9 billion by 2050), increasing demands for meat and dairy products, and the challenges of climate change may result in food shortages (Godfray *et al.* 2010). This driver will impact on Enclosed Farmland indirectly by influencing markets and policies to increase food production at the potential expense of other services.

7.2.2.7 Technological adaptation and knowledge

The impacts of technology as a driver of ecosystem service delivery from Enclosed Farmland cannot be exaggerated. The replacement of draught animals by tractors removed the need to grow cereals to feed them (Chapter 15), while the introduction of inorganic fertilisers removed the need for manures for arable crops (Shrubb 2003). The result was the polarisation of Enclosed Farmland between the arable east and pastoral west that can be seen today (**Figure 7.2**; Robinson & Sutherland 2002; Haines-Young *et al*. 2003). Loss of livestock, plus economies of scale for use of machinery, led to large increases in field size and the loss of field boundary habitats and ponds in the arable areas of the east.

From the 1970s, the process of agricultural intensification and increased productivity was associated with the widespread use of several technologies including agrochemicals and new varieties and breeds (Chamberlain 2000). For example, genetic improvement explains more than 50% of the milk productivity improvements seen on UK farms over the past two decades (The Smith Institute 2009). However, there was widespread concern that agricultural production was being promoted at the expense of other ecosystem services and human well-being (McIntyre *et al.* 2009). Policy responses included agri-environment schemes and regulations such as the Water Framework Directive (WFD); consumer responses included resistance to GM crops and increasing markets for food produced locally and less intensively; and technological responses included ways to manage agrochemical and nutrient inputs through precision, integrated and organic farming systems.

Precision farming systems use technology to help the grower to manage inputs more exactly, for example, using soil mapping and GPS to locate precisely where fertilisers should be applied. Therefore, they facilitate the optimal use of farm inputs, reducing costs, maximising yields and reducing environmental impacts. However, take-up is low; in England in 2009, the percentage of holdings using precision technology was divided thus: GPS, 11%; soil mapping, 14%; yield mapping, 7%; rate application, 13%; telemetry, 1%; guidance, 11%; and auto steering, 6%. The nutrient content of soil was regularly tested on only 68% of holdings (Defra 2010a).

Integrated Farm Management is a whole farm system intended to provide efficient and profitable production that is environmentally responsible. It integrates beneficial natural processes into modern farming techniques, ensuring that high standards of stewardship and environmental care are practised. In the UK, integrated farming is promoted by Linking Environment and Farming (LEAF; www.leafuk.org/leaf/home.eb). For instance, parasitoids and predatory insects, such as carabid and staphylinid beetles, that eat crop pests like aphids can be encouraged through the provision of rough grass banks in field centres or along field edges (Collins *et al.* 2003), reducing the need for summer aphicides. The abundance of flying predators of aphids has been shown to have a greater impact on aphid numbers than the abundance of epigeal predators, independently of grass margins immediately adjacent to the crop (Holland *et al.* 2008). In addition, pollinator numbers can be enhanced using nectar-rich plant mixtures in field margins (Carvell *et al.* 2007).

Organic farming promotes the internalisation of inputs for crop and livestock production (especially in the case of nutrients), precludes the use of many external inputs, such as mineral fertilisers and most pesticides, and incorporates biological processes such as pest control by rotation (Lampkin 1990; Norton *et al.* 2009b). Production levels are typically lower than non-organic systems, but prices are normally higher than other farm products. National standards for organic production and labeling, such as those of the UK Soil Association, are underpinned by European Council Regulation 834/2007. In 2008, the total area of land that was organically managed (either fully organic or in-conversion) was 743,000 ha, half of which (375,000 ha) was in England. In all, there were 320,000 cattle, 1.2 million sheep, 71,000 pigs, 4 million poultry and 5,000 other livestock being reared organically in the UK (Defra 2010a). Organic farms are concentrated in south-west England, where climate, soils and topography are unfavourable for intensive arable farming and facilitate the rotations involving both crops and livestock that enable the efficient use of organic nutrients. Here, the proportion of registered organic farmers reaches 29% of crop producers and 27% of livestock farms.

It is now argued that the medium-term threats to food security require new technological investment. The goal is to increase production but without compromising the delivery of other ecosystem services (Royal Society 2009). There is new interest in technologies aimed at promoting the co-management of multiple ecosystem services. For instance, genetic improvement, diet manipulation and containment are increasingly being adopted to reduce greenhouse gas emissions from livestock (Abberton *et al.* 2007; Garwes 2009). Technologies that could be applied to adapt to summer droughts in arable areas include more water-efficient crops, irrigation systems with high efficiency (such as low pressure sprinklers), drip irrigation, the use of sub-surface partial root drying (PRD) systems, the use of greenhouses and plastic tunnels, and the use of non-conventional water resources (brackish groundwater, treated waste water, rainfall-harvested water, etc.). Genetic Modification technology will remain an important option for the development of new crop varieties with, for example, improved drought tolerance, among other qualities.

7.2.2.8 Market forces

Farmers typically aim for profit maximisation in the light of farm climate and soil type, as well as prices, grants, exchange rates, etc. (Bateman *et al.* 1999). Normally, this results in yields less than maximum because a point is reached where additional input costs are not recouped by returns on marginal increases in outputs. Changes in global market conditions and policy can bring a rapid response by farmers; for example, in 2007, the area of uncropped land (set-aside and fallow land) fell by over one fifth following rising cereal prices and the removal of the requirement for farmers to set aside land under the CAP (Section 7.2.2.9).

Over the last half-century, agri-food systems have become more integrated, with supermarkets increasing in size and increasing their market share and control over the whole supply chain, from farm to shop. Meanwhile, fragmented markets supply more of the higher-value products including organic and local food (McIntyre *et al.* 2009). Sales of organic produce accounted for only 5.3% of total fruit and vegetable sales in 2006, most of which was imported (The Smith Institute 2009). Supermarkets are increasingly promoting local produce and reduced environmental impact throughout the food chain in order to meet the markets for more environmentally and socially benign consumption.

Markets in the UK operate using various standards and assurance schemes. For example, for the milling of bread flour, the protein levels of wheat must normally exceed 13% of dry matter. Otherwise, it is sold more cheaply for animal feed. The setting of this level influences both farm management decisions and the proportion of crop production that can be sold directly for human food. Between 2000 and 2008, an average of 49% of the UK annual wheat crop was used for animal feed and 42% for flour (Defra 2010a).

Consumer concerns about intensive agriculture came to a head in the debate about the introduction of GM crops that started in the late 1990s. While the first GM product in the UK market place sold well, consumer resistance built up, making the approval of the first commercial planting of GM crops (a herbicide-tolerant variety of maize) very contentious. The UK Farm Scale Evaluations (FSEs) were established to improve the evidence base for the environmental risks of herbicide-tolerant maize, sugar beet, spring and winter oilseed rape (Firbank *et al.* 1999). They found that environmental impacts resulted from the herbicides used on the crops, not from the way in which the crops themselves had been developed (Firbank *et al.* 2003a). This project was intended to provide part of the evidence for the much wider assessment of environmental and health risks required to approve any releases of GM organisms. However, this was only one of the concerns expressed in public debates held at the time of the FSEs; concerns also included risks to human health, food safety, the power of multinational agrochemical companies, and the contamination of non-GM and organic produce. At present, there is no commercial planting of GM crops in the UK, and very little across Europe.

7.2.2.9 Government subsidies and regulation

The Common Agricultural Policy (CAP) and agri-environment schemes. Following the food shortages of WWII, the 1947 Agriculture Act mandated an intensification of food production to ensure self-sufficiency, which was facilitated by price support (Tracy 1989). Price support for increased productivity continued following the UK's accession to the EEC in 1973 and the implementation of the CAP (Young *et al.* 2005). These policies were highly successful, to the extent that, in the early 1980s, the CAP changed in emphasis, introducing measures to control surplus production. These actions included the imposition of milk quotas in 1984 and the introduction of set-aside from 1987. Set-aside involved taking arable land out of food production. While this measure was economic in intent, it also provided food and habitats for many farmland species as large areas of land were allowed to regenerate naturally (Firbank *et al.* 2003b). Environmental benefits were sought more actively through the UK's first agri-environment scheme in 1987 (see next paragraph). Subsequent CAP reviews in 1992, 1998 and 2003 increased support for environmental management and for activities other than food production (Bignal & McCracken 2000; Bignal *et al.* 2001; Dwyer *et al.* 2007). The 1992 CAP reforms 'fossilised' existing patterns of arable land use to a significant extent (Winter 2000). Most financial support provided to farmers is no longer dependent on them growing specific areas of crops or retaining a certain number of animals. Instead, a Single Payment Scheme is available to farmers, provided they meet cross compliance standards (ADAS 2009). That is, they undertake to comply with a range of conditions to ensure basic standards of environmental management, animal welfare and food safety, and keep their land in Good Agricultural and Environmental Condition (GAEC).

The main policy vehicles for delivering ecosystem services other than food production from Enclosed Farmland are agri-environmental schemes developed within the CAP, in which farmers are paid to manage the land for particular environmental benefits. Starting with the Environmentally Sensitive Areas Scheme in 1987, these have evolved differently in each country in the UK. More than 8 million ha of farmland in the UK are currently managed under agri-environment scheme agreements, although the actual area covered by specific agri-environment scheme management plans within farms is much smaller (Defra 2010a).

In England, the most recent scheme is Environmental Stewardship. This currently takes the form of Entry Level Stewardship (including an organic version), which is non-competitive and based on a threshold of points awarded for management measures, and the Higher Level Stewardship, which is targeted and competitive and provides funding towards more specific environmental management actions (such as habitat and species maintenance and enhancement, pollution mitigation, flood prevention, etc.). In 2009, there were 1,000 ha still in the Organic Farming Scheme (the predecessor of Organic Entry Level Stewardship), 372,000 ha still in the Countryside Stewardship Scheme (a predecessor of Environmental Stewardship), 462,000 ha still in the Environmentally Sensitive Areas Scheme, 5.6 million ha under Entry Level Stewardship and 453,000 ha under Higher Level Stewardship (Defra 2010a).

In Wales, Tir Gofal is a comprehensive scheme and is applicable on a whole farm basis throughout the country, while Tir Cynnal is a less demanding 'entry level' scheme. In 2009, there were 377,000 ha in Tir Cymen/Tir Gofal and 281,000 ha in Tir Cynnal, along with 126,000 ha still in the older Organic Farming/Maintenance Schemes and 26,000 ha still in the Environmentally Sensitive Areas Scheme (Defra 2010a). From 2012, these schemes will be replaced by a single scheme, Glastir.

In Scotland, in 2009, 115,000 ha were in the Organic Aid Scheme, 174,000 ha were still in the Environmentally Sensitive Areas Scheme, 239,000 ha were in the Countryside Premium Scheme/Rural Stewardship Scheme, and 492,000 ha were in Land Management Contracts/Land Managers Options (Defra 2010a).

In Northern Ireland, in 2009, 468,000 ha, or 39% of farmland, was registered in an agri-environment scheme, including 7,000 ha in the Organic Farming Scheme, 352,000 ha in the Countryside Management Scheme, and 109,000 ha in the new Environmentally Sensitive Areas Scheme.

These payments have largely resulted in the preservation of existing habitats and features. For example, in England, 41% of hedgerows are now managed through the schemes and more than 6,000 archaeological features on farmland are protected under the schemes, including more than half of all scheduled monuments and registered battlefields (Natural England 2009a). There have also been benefits to educational access and landscape quality (Carey *et al.* 2003). New areas of habitat have been created, notably 116,000 km of grass buffer strips. Recent agri-environmental and set-aside policies are thought to be responsible for the 5.4% increase in enclosed grassland between 1998 and 2007 (Carey *et al.* 2008), restoring some landscape diversity to arable landscapes, although some of this area has since been returned to arable cropping (Section 7.2.2.8). They have produced increases in species abundance, yet so far only when focused on designated sites and targeted actions for particular range-restricted populations or experimental pilots (Aebischer *et al.* 2000; Kleijn & Sutherland 2003; Wilson *et al.* 2009). For instance, Countryside Stewardship projects helped cirl buntings (*Emberiza cirlus*) in England to increase by 133% between 1993 and 2009, and corncrakes (*Crex crex*) in Scotland to increase by 181% between 1994 and 2008 (McCracken & Midgley 2010). Widespread deployment of agri-environment scheme agreements has so far failed to reverse national declines of widespread species (Section 7.3.5). This may be because these schemes have had insufficient time to take effect, although there is also evidence that the most commonly adopted agri-environment measures are not necessarily those that benefit wildlife the most (Butler *et al.* 2007; McCracken & Midgley 2010).

Support for farm woodlands. The establishment of farm woodlands on land formerly in agricultural use has been supported by grants that compensate farmers for loss of agricultural income. The Woodland Grant Scheme (WGS), the Farm Woodland Scheme (FWS) and their successors led to the establishment of about 120,000 ha of new woodland between 1988 and 2005 (Usher *et al.* 1992; John Clegg *et al.* 2002; Forestry Commission 2009). Many of these woodlands have been created to support game shooting and wildlife conservation, rather than timber production (Duckworth *et* *al.* 2003). The impacts of woodland creation depend on a variety of factors including the taxa observed, and the size and location of the woodland (Usher *et al.* 1992; Usher & Keiller 1998).

Support for bioenergy. The UK aims to obtain 15% of all its energy from renewables by 2020, a target which will require significant increases in the contribution of renewables to each of the three energy sectors: electricity, heat and transport. While opportunities to use materials such as municipal solid waste and forestry waste are considerable (Gove *et al.* 2010), agricultural bioenergy in the form of biomass or biofuel crop products, or biogas from anaerobic digestion of agricultural or food waste, can contribute to each of the energy sectors.

The planting of perennial biomass crops on more marginal land is being encouraged to help relieve potential conflicts over land use (Lovett *et al.* 2009). Government incentives have been introduced to encourage establishment of bioenergy crops (e.g. Natural England's 2010 Energy Crops Scheme). The UK Biomass Strategy (DTI, DFT & Defra 2007) concluded that 350,000 ha of perennial energy crops were needed by 2020; this could be achieved without greatly affecting food production if they are grown on less productive land (Lovett *et al.* 2009). This forecast needs to be set against current biomass crop production, comprising willow from SRC and *Miscanthus* of 15,500 ha, indicating that a sharp increase in area of production is needed to meet demand. At present, a considerable amount of material, including timber and oil palm co-products, is imported to plug this gap (Gove *et al.* 2010). This analysis also excludes the estimated 740,000 ha required to grow crops for transport fuels (Booth *et al.* 2009).

Targets and regulations. Standards of environmental management of Enclosed Farmland are being set through European-wide legislation. In particular, the WFD sets objectives to improve the chemical and ecological status of watercourses, groundwater and coastal waters by 2015, and is likely to have a major impact on the way agricultural land is managed, as currently exemplified by the England Catchment Sensitive Farming Delivery Initiative (McCracken & Midgley 2010). The Scottish Environment Protection Agency and the Scottish Government have recently announced a new target for the restoration of Scotland's water bodies: they aim to bring 97% into 'good status' by 2027. This is very ambitious, especially as the hydrological cycle is likely to be altered by climate change, and changes in the amount, timing and distribution of precipitation and runoff will lead to changes in water availability.

Targets are also being established for improvements in climate regulation from Enclosed Farmland. These focus on reductions in emissions of the greenhouse gases methane and nitrous oxide, as they have high global warming potentials (carbon dioxide equivalent (CO_2e) values of 72 and 289 over a 20-year time horizon, respectively), and agriculture is a major source, accounting for 38% of all UK methane emissions and 69% of all UK nitrous oxide emissions in 2008 (Defra 2010a; Section 7.3.2.1). For example, the UK Low Carbon Transition Plan encourages English farmers to make and maintain a reduction in greenhouse gas emissions to a level (3 megatonnes (Mt) of carbon dioxide emissions) at least 11% lower than currently predicted for 2020. To help meet this ambition, a farming industry Greenhouse Gas Action Plan was developed and published in February 2010 by the Climate Change Task Force. The Welsh Assembly Government set up an independent Land Use Climate Change Group in January 2009, which developed recommendations for reducing emissions by 2040 (CCC 2010). At the time of writing, the Welsh Assembly Government is reviewing report recommendations in order to develop an action plan to take forward various mitigation proposals. Scotland published its Climate Change Delivery Plan in June 2009, which proposes a reduction target for the agricultural land use sectors of 1.3 Mt CO_2 emissions by 2020. Northern Ireland's Department of Agriculture and Rural Development (DARD) established an internal Steering Group during 2009 to develop a range of primary production mitigation measures based on a review of available scientific evidence.

7.3 Ecosystem Goods and Services Provided by Enclosed Farmland for Human Well-being

An overview of the provision of the UK NEA classification of goods and services by Enclosed Farmland is shown in **Table 7.3**.

7.3.1 Provisioning Services

7.3.1.1 Food

The vast majority of parcels of Enclosed Farmland are managed primarily for a single ecosystem service, the provisioning of food, either directly for human consumption or feed for livestock. This service is met by the removal of large amounts of net primary production and the manipulation of nutrient cycles**.**

During the 19th Century, arable crops were usually grown within a rotation, most commonly the Norfolk four-course rotation of turnips, spring barley, clover or a grain, legumes and wheat (Johnston & Poulton 2009). Pest and disease infestation greatly limited yields and there was little understanding of basic crop nutritional requirements, with the exception that livestock manure boosted yields which was generally only applied to the most valuable root crops in the rotation. Agricultural productivity per unit area grew four-fold after WWII (Defra 2010a; Chapter 15), driven by the introduction of high-yielding varieties of crops, an ability to control pests and diseases effectively, and an all-round effective agronomy (including the introduction of selective herbicides and fungicides, and more effective use of nitrogen), supported by deliberate policy interventions. The relationship of wheat yields to these technological changes can be seen in the record of the long-term Broadbalk Experiment at Rothamsted Research (**Figure 7.7**); more than 90% of yield improvement in winter wheat over the

Table 7.3 Overview of final ecosystem services provided by Enclosed Farmland. Note: the impact values range from ++ to --, depending on the magnitude and direction of influence. ⦿ denotes high agreement with much evidence; ⊙ indicates high agreement with limited evidence. Ecosystem services are categorised as provisioning (P), regulating (R) or cultural (C).

Final ecosystem service	Importance of enclosed farmland for service	Impact of enclosed farmland on service	Evidence base	Comments
Crops, plants, livestock, fish, etc. (wild and domesticated)	High	++	⦿	Strong positive score: farmland is largely managed for crop and livestock production.
Trees, standing vegetation & peat	Low	+	⊙	Positive score, due to small but increasing areas of biomass crops.
Climate regulation	High	--	⦿	Strong negative score, due to emissions of Greenhouse gases and depletion of carbon in soils.
Water quantity	High	+ / -	⦿	Important for catching water for ground and surface waters, though flood risk mitigation potential often compromised by management.
Hazard regulation –vegetation & other habitats	High	--	⦿	Negative impact on sediment loss to watercourses, increasing flood risk downstream.
Waste breakdown & detoxification	High	-- / +	⦿	Negative score due to diffuse (mainly) pollution leaving farmland; positive score for ability to compost green waste / AD, and sewage disposal.
Wild species diversity including microbes	High	--	⦿	Negative impacts; status of microbes unknown.
Purification	Low	--	⦿	Negative impacts on water quality as a result of diffuse pollution.
Environmental settings – meaningful places incl. green & blue space	Low	Zero	⊙	Individual sites have less significance than spaces in cities or mountain tops.
Environmental settings – socially valued landscapes and waterscapes	High	++	⊙	Farming management is largely responsible for the landscapes that many people cherish.

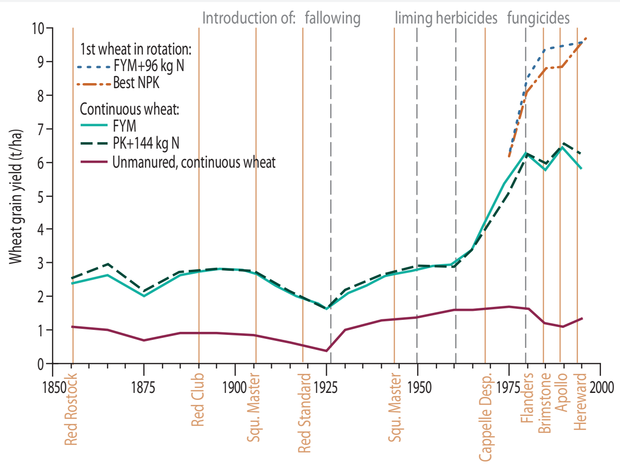

Figure 7.7 Yields of wheat grain (t/ha) through time on the Broadbalk Wheat Experiment at Rothamsted Research, plotted against variety, fertiliser treatment and agronomy (liming, herbicides, etc.). Source: reproduced from Goulding *et al.* (2009), with permission from the Philosophical Transactions of The Royal Society B.

past 25 years has been due to new varieties that are able to respond to the application of fertilisers, although the use of pesticides has also been important. Over the past decade, there is little evidence of national yield increases in wheat, barley or oilseed rape, in spite of the regular introduction of new varieties with higher yields in experimental plots. This may be due to farmers managing the crop to maximise profit rather than yield, and also to more variable weather patterns (The Smith Institute 2009).

In grassland systems, both yield and digestibility of grass have increased greatly since 1945 (Hopkins 1999), while high milk-yielding Holstein Friesians have been crossed with breeds such as Herefords and Simmental to produce beef from dairy herds. Steady improvements in the efficiency of beef and sheep production have taken place over the past decade, resulting from improved genetics, fertility and feeding, better health measures, the use of artificial insemination, and industry-wide development and knowledge transfer initiatives. Genetic and management improvements in dairy cattle have seen the average cow increase milk production from 5,000 litres/year in 1989 to 7,600 l/yr in 2007 (The Milk Roadmap 2008), while the number of animals required to produce each tonne of meat fell by 5% from 3.23 in 1998 to 3.07 between 1998 and 2008 (EBLEX 2009). For more details on yield increases see Chapter 15.

Current levels of production mean that the UK is 60% self-sufficient in all foods, and 73% self-sufficient in indigenous foods (UK Agriculture 2010; Chapter 15; Chapter 21; **Figure 7.8**). In 2009, the area of cereals planted in the UK was 3.1 million ha, producing just over 22 million tonnes of grain (Defra 2010a). Cereal production in the UK is now worth over £2.5 billion and is more than sufficient for the country's processing needs. Exports total 2–4 million tonnes, depending on the season, while the UK imports about 1 million tonnes of bread-quality wheat (The Smith Institute 2009). Between 1988 and 1993, approximately 55% of the fruit and vegetables consumed in the UK were domestically produced; subsequently, production went into decline and the proportion fell to 33% in 2006.

For most of the period since the 1980s, the UK's imports and exports of milk and other dairy products have broadly balanced. However, from 2004, the UK became a net importer. The main dairy herd was 1.9 million animals and the beef herd was 1.6 million animals, while there were 32 million sheep and lambs. The female pig breeding herd was 445,000 animals, and the poultry breeding flock was 9.6 million birds, but neither fulfilled all of the UK's needs (**Figure 7.8**). Today, UK farms produce 1.1 million tonnes of meat (EBLEX 2009) and over 13 billion litres of raw milk each year, around 6 billion litres of which is processed into liquid milk, mainly for drinking (The Milk RoadMap 2008; **Table 7.4**). In addition, the UK imports a further 1.1 billion l of milk (The Smith Institute 2009).

The contribution of food production to the UK GDP has fallen from almost 3% in 1973 to 1.5% in 1996 and around 0.6% in 2009, although the agri-food sector as a whole contributes 6.7% (Defra 2010a). In 2008, agriculture's share of Gross Value Added was greatest in Northern Ireland (1.20%) and least in England (0.56%) (note: these figures include production from the uplands as well as from Enclosed Farmland). Recent trends in the production, value and self-sufficiency of wheat, and a selection of other agricultural commodities produced principally on Enclosed Farmland, are shown in **Figure 7.8**, while trends in trade of various commodities are shown in **Figure 7.9.** These data shows the sharp rise in food prices in 2008. The real costs of major foods to UK consumers have also declined: in 1973, 19.7% of final household expenditure was on household food; by 2008 it had fallen to 8.8% (Defra 2010a).

7.3.1.2 Wild food

Enclosed Farmland provides a number of species that are valued as food such as field mushroom, blackberry and watercress (Mabey 1972). In addition, gamebirds and mammals are shot as part of crop protection activities (e.g. deer, rabbits (*Oryctolagus cuniculus*), pigeons) and recreational shooting (e.g. grey partridge, red-legged partridge (*Alectoris rufa*), pheasant). Although game species are technically wild animals, many are non-native and the subject of often intensive management. Many game species are hunted for pleasure, but, despite this, the majority of game animals that are killed in the UK will enter the human food chain in some form, either by being eaten by their hunter or after being sold to consumers, retailers or game dealers (see Chapter 15 for more detailed accounts of particular game species).

7.3.1.3 Bioenergy

The production of bioenergy is currently low but is expected to increase over the coming decade. Kilpatrick *et al.* (2008) suggested that the biomass resource required to achieve

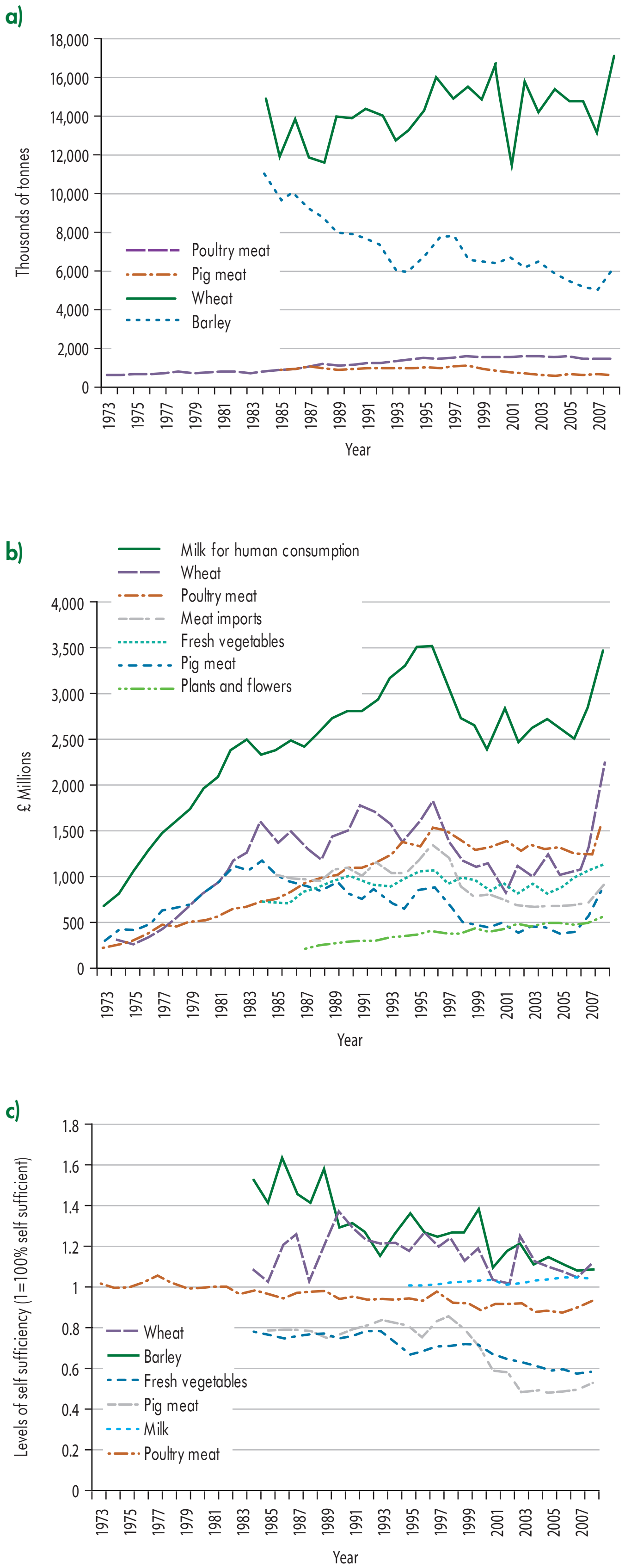

Figure 7.8 a) Amount (thousand tonnes) of production, b) value of production (£ million at market prices) and c) levels of self-sufficiency of exemplar agricultural products for the UK over time. Data focuses on those goods for which production is based in Enclosed Farmland, excluding protected crops. Source: data from Defra (2010a).

Table 7.4 Production of major agricultural commodities in the UK in 2008. At the time of writing, 2008 was the most recent year for which confirmed data were available. Data for cattle and sheep meat include production from non-enclosed farmland. Source: data from Defra (2010a).

Commodity	Production	Value at market prices	% of new supply for use in UK
Wheat	17 million tonnes	£2,245 million	110
Barley	6.1 million tonnes	£817 million	108
Oats	780,000 tonnes	£90 million	110
Oilseed rape	2.0 million tonnes	£618 million	102
Linseed	30,000 tonnes	£10 million	111
Sugar beet	7.6 million tonnes	£208 million	60 *
Potatoes	6.1 million tonnes	£767 million	82
Fresh vegetables	120,000 hectares	£1,104 million	58
Plants and flowers	20,000 hectares	£799 million	-£897 million †
Total fruit ‡			11
Orchard fruit	18,000 hectares	£145 million	
Soft fruit	10,000 hectares	£359 million	
Beef and veal ¶	860,000 tonnes	£2,068 million	82
Pigmeat¶	710,000 tonnes	£867 million	52
Mutton and lamb ¶	330,000 tonnes	£798 million	88
Poultrymeat ¶	1.5 million tonnes	£1,578 million	92
Milk §	13,000 million litres	£3,447 million	104
Hen's eggs	750 million dozen	£520 million	79

* refined sugar.
† % supply not available, here we give trade gap of value of exports—value of imports x gross indigenous production.
‡ % supply only available for total fruit.
¶ dressed carcass weight, gross indigenous production.
§ for human consumption.

Table 7.5 Likely impacts of biomass crops on ecosystem services and biodiversity. ↑ positive impact; ↓ negative impact; ↔ no change; * limited data. Source: Rowe *et al.* (2009). Copyright (2009), reproduced with permission from Elsevier.

Environmental impact	Short rotation coppice (SRC)	*Miscanthus*	Biofuel crops (wheat, oilseed rape, sugarbeet)
Soil organic carbon	↑	↑	↔
Nitrogen leaching	↑↑↑	↑↑↑	↔
Visual impacts	↓	↓	↔
Energy and carbon balance	↑↑↑	↑↑↑	↑
Hydrology (at catchment scale)	↓	↓	↔
Biodiversity	↑↑	↑ *	↔
Avian	↑↑	*	↔
Flora	↑↑	*	↔
Invertebrates	↑↑ *	*	↔
Mammal and amphibians	*	*	↔

policy targets (Section 7.2.2.9) can be generated from straw from cereals and oilseed rape, along with energy and root crops on arable land. Much greater changes in land cover may occur on grassland, with the conversion of temporary grassland to energy crops and the conversion of permanent grassland and rough grazing to short rotation forestry (SRF).

The impacts on other ecosystem services depend greatly on how and where the bioenergy crops are introduced and managed (Firbank 2008; Lovett *et al.* 2009; Karp *et al.* 2009, Rowe *et al.* 2009; **Table 7.5**). The major benefit would be in terms of contribution to climate regulation. In theory, perennial crops, such as SRC, SRF and *Miscanthus*, can be close to carbon neutral because the quantities of carbon dioxide released to the atmosphere on combusting the crop are equal to those absorbed by photosynthesis during crop growth. The production of energy from straw entails only minimal additional carbon inputs over and above the food crop within the field. There are additional net carbon dioxide emissions associated with the management, harvesting and transport of bioenergy crops, and, in some instances, there may be loss of soil and vegetation carbon from the habitats bioenergy crops replace, although using arable soils for *Miscanthus* increases soil carbon stocks. Therefore, the total greenhouse gas mitigation potential of energy crops depends largely upon how they are grown, the energy costs of transport and the land use which they replace (St Clair *et al.* 2008; Hillier *et al.* 2009; Gove *et al.* 2010). Booth *et al.* (2009) suggest that replacing 12% of the total cropped area on an example arable farm with SRC would reduce total greenhouse gas emissions by 10.3%, mainly as a result of lower fertiliser use reducing nitrous oxide emissions. This reduction would be 7.7% if SRC willow replaced 12% of Improved Grassland area on an example mixed livestock farm (producing beef and lamb on a grass-based system), largely achieved by a reduction in livestock numbers.

Perennial bioenergy crops have high water requirements that would need to be accounted for in planning water regulation, but they have low nutrient requirements, with

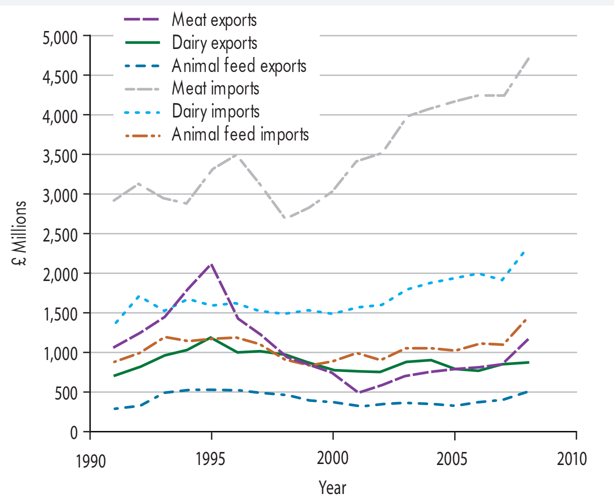

Figure 7.9 UK trade in meat, dairy and animal feed with the rest of the world (£ million at 2008 prices). Source: data from Defra (2010a).

little risk of diffuse pollution. Biodiversity should benefit, too: SRC and SRF would provide new habitats for taxa of small woodlands and perennial crops should not result in major impacts on species if planted on species-poor grasslands and avoiding locations important for species of open habitats. As *Miscanthus* is not native to the UK, it may support less biodiversity than SRC, and its biodiversity value may decline as it matures due to increased crop density. Plantings of energy crops could also be planned not to compromise the landscape quality of culturally valued areas.

7.3.2 Regulating Services

Enclosed Farmland regulates biogeochemical cycles of water, nutrients and carbon. Soil organisms cycle nutrients and carbon, though our understanding of the mechanisms by which soil biodiversity influences ecosystem processes and the delivery of supporting services, and how it responds to land management, is limited (Bardgett & Wardle 2010). The status of soil microbial and fungal functional diversity and their trends remains under-researched at the national level; although there is evidence that they can contribute to soil moisture retention and the attenuation of runoff, for example (Allton *et al.* 2007). The large area of Enclosed Farmland gives it a potentially important role in regulating services. However, current agricultural management often generates emissions of greenhouse gases and releases nutrients to air and water, resulting in Enclosed Farmland causing net disbenefits.

7.3.2.1 Climate regulation

Here, we focus on carbon sequestration, storage and greenhouse gas emissions within the fields and housing for livestock; emissions from the rest of the food chain are excluded from this analysis.

Permanent grassland soils are already close to carbon saturation (Bradley *et al.* 2005), making them important carbon stores rather than potential sinks. The large-scale loss of permanent grassland during the 20th century must have resulted in large releases of carbon (Smith *et al.* 2000a,b): they currently hold around 43 t/ha in the top 15 cm, which is a decline from 1998. Meanwhile, stocks under Improved Grassland have remained steady at 61 t/ha (Carey *et al.* 2008). Conversion of temporary grassland or arable to permanent grassland or woodland will tend to lead to an increase in carbon sequestration, and the cessation of cultivation (especially of peat soils) will reduce carbon dioxide losses (Smith *et al.* 2008). Some techniques may help to enhance soil carbon in arable soils, for example, the input of organic materials such as green waste compost or digestate material derived from anaerobic digestion (Banks *et al.* 2009). In general, however, inputs of organic materials maintain soil carbon or slightly uplift the equilibrium level, resulting in a state which then needs to be maintained by continued inputs. Evidence of the success of no-tillage and minimum tillage regimes for maintaining and enhancing soil carbon is equivocal (Baker *et al.* 2007; Bhogal *et al.* 2008; Smith *et al.* 1998, 2008).

Despite this sequestration and store potential, UK agriculture generates net greenhouse gas emissions (**Figure 7.10**). Indeed, emissions from agriculture account for around 7.0% of the UK total, although there is variation between UK countries (LUCCG 2010).

While nitrous oxide emissions (53% of total agriculture emissions in 2008) arise naturally in agricultural soils through biological processes, they are especially associated with the oxidation of the nitrogen in inorganic and organic fertilisers on both arable and grassland. Emissions are greatly influenced by a variety of agricultural practices and activities, including the quantity of fertiliser applied, the deposition of manure onto soils by grazing animals, the nitrogen in crop residues returned to soils, the timing of fertiliser application, and other land management practices (such as drainage) which affect the proportion of nitrogen taken up by the crop, retained in the soil or released as nitrous oxide or other pollutants (CCC 2010).

Methane emissions (38% of agriculture emissions in 2008) within the agriculture sector mainly arise from enteric fermentation that occurs in the digestive systems of ruminants (e.g. cattle and sheep) and from manures. They are driven by the number of livestock animals, the characteristics of those animals (i.e. their breed, size, yield, digestive systems, etc.), what livestock are fed (for example, a diet with a higher maize content can maintain animal performance while decreasing the production of methane), and how manures are managed (CCC 2010).

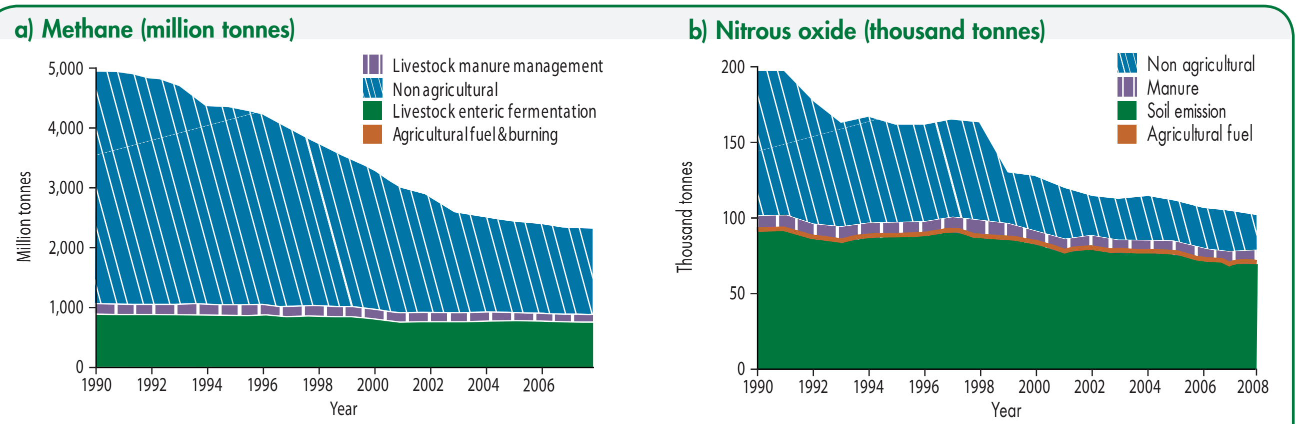

Figure 7.10 UK emissions of a) methane and b) nitrous oxide from agricultural and other sources. Source: Defra (2010a). © Crown copyright.

Carbon dioxide from agriculture accounts for less than 1.0% of the UK total, and is generated from the use of machinery in agriculture and, to some extent, from soil disturbance.

Since 1990, agricultural greenhouse gas emissions have fallen from 61 Mt CO_2e to 48 Mt CO_2e, decreasing from all direct sources: soils (-23%), enteric fermentation (-16%), wastes/manure management (-21%), and stationary/mobile combustion (-19%). Agricultural emissions have also declined across the range of greenhouse gases: nitrous oxide (-23%), methane (-18%) and carbon dioxide (-19%). Reductions in nitrous oxide emissions have been concentrated on grassland and are correlated with decreased fertiliser use (Defra 2010a), while reductions in methane emissions have resulted largely from decreases in the sizes of animal herds (note: there is an assumed correlation between animal numbers and emissions from manure management as the latter is calculated from the former) (CCC 2010). While reductions in ruminant numbers have had the greatest impact on agricultural emissions in the UK to date, these reductions contribute to improved climate regulation only if ruminant numbers do not increase elsewhere as a result of shifts in trade (Gill *et al.* 2010). Also, rising nitrous oxide emissions from fertiliser use is more than offsetting the reduction in methane emissions from lower livestock numbers, so much so that, without additional interventions, Scottish emissions from agriculture are projected to rise slightly in the future to about 7.3 Mt CO_2 emissions/yr in 2020 (Slee *et al.* 2009).

There is potential to reduce greenhouse gas emissions from arable systems through improved soil, fertiliser and agrochemical management (Smith *et al.* 2008; Macleod *et al.* 2010). Nitrous oxide emissions arising from crops and soils can be decreased by good nutrient planning, including improving efficiency in using fertiliser by, for example, taking full account of nitrogen in manure applications, timing applications to match crop requirements, using composts and straw-based manures in preference to slurry where practical, and separating slurry and mineral nitrogen application. Reductions in fertiliser use will also have emissions benefits beyond the farm gate, as fertiliser manufacture and transport is associated with high industrial carbon oxide emissions (CCC 2010). Other mitigation options include soil management measures (such as improved drainage), the use of nitrification inhibitors (which can reduce nitrous oxide emissions arising from fertiliser application, but do not necessarily lead to a reduction in fertiliser application levels), and the use of more nitrogen-efficient plants (including the introduction of different species) (CCC 2010).

There is scope to reduce greenhouse gas emissions from the livestock sector per kilogram of product (EBLEX 2009). Animal diet can have a profound impact on emissions. For instance, the poorer quality nutrition and longer production times of hill sheep mean that much higher greenhouse gas emissions per kilogram of lamb are produced because lower quality forages tend to generate higher methane emissions and slow growth results in greater emissions than more rapid growth and earlier slaughter. Thus, lowland sheep flocks produce 12.6 kg CO_2e/kg, compared to upland flocks (13.8 kg CO_2e/kg) and hill flocks (18.4 kg CO_2e/kg) (EBLEX 2009). Gaseous emissions from livestock systems can, therefore, be reduced by breeding to influence productivity and fertility (respecting animal welfare concerns), modifications to diet to reduce enteric fermentation (such as using maize-silage instead of low quality forage that stimulates methane production), and, subject to satisfactory resolution of animal welfare concerns, a shift to utilising dietary additives such as propionate precursors (CCC 2010). Methane emissions from stored manures and slurries can be reduced through the installation of on-farm or centralised anaerobic digestion plants to generate energy, and by covering and aerating slurry and manure while stored (CCC 2010). However, many of these practices are not yet widely adopted.

7.3.2.2 Water quantity, hazard regulation, waste breakdown and detoxification, and purification

The management of Enclosed Farmland has large impacts on the management of water, pollutants and waste products, not least because of the large areas of land involved. Farmland can be both a source and a sink for waste and toxins. As these functions are interlinked through hydrological and biogeochemical processes, they are considered together here.

Water quantity and flood risk. River water and groundwater are important resources for agriculture. Although water used for agriculture represents about 2.0% of that abstracted in the UK, much is used in the south and east of England during summer, already areas of particular pressure for water resources (Defra 2010a). Also, 62% of water needed to produce goods consumed in the UK is so-called 'virtual water', i.e. embedded in the water needed to produce those goods (agricultural and non-agricultural) overseas (HM Government 2010; Chapter 21). Recently, WWF estimated the water needs for agricultural production in the UK at 34,000 million m^3/yr, with a net UK water footprint of 28,000 million m^3 /yr, contrasting with an external footprint of 46,000 million m^3/yr of food imported into the UK (Chapagain & Orr 2008).

Agricultural use of water can have both positive and negative contributions to flooding, soil erosion and the recharge of aquifers. Plant cover, root architecture, drainage and field and watercourse boundary management all contribute to speeding up or slowing the movement of water across farmland, albeit at a local level, and these effects are easily masked at the catchment scale. Under waterlogged conditions agriculture is very severely restricted, so much agricultural land is drained in order to shift water off the land surface as quickly as possible; this increases the flood risk downstream, however. In addition, biomass crops are fast-growing and consume large amounts of soil water which can, in turn, have a negative impact on groundwater recharge. By contrast, grasses, trees and other waterside vegetation can slow down runoff and help reduce diffuse pollution (Pilgrim *et al.* 2010; Bilotta *et al.* 2007). Some Enclosed Farmland in floodplain areas is managed through grazing to hold water and contribute to flood management, but the size of such areas declined considerably during the 20th Century, in conjunction with increased river canalisation.

Powered cultivation and the loss of field margin vegetation can lead to increased loss of sediment to watercourses, reducing habitat quality for biodiversity (including economically important salmonids), blocking channels and increasing flood risk. Analysis of sediment cores in recent years has revealed that sedimentation of UK reservoirs has intensified in response to an increase in arable area and the adoption of field drains, thus contributing to reduced water storage capacity (Foster 2006).

Air quality. The major impacts of the management of Enclosed Farmland on air quality are the emissions of methane (covered in Section 7.3.2.1) and ammonia. Ammonia is a nitrogen compound released by the breakdown of urea and uric acid from urine, poultry faeces and inorganic fertilisers. It can be dispersed through the air and in rainfall, to be deposited on soils and vegetation, acidifying and adding nitrogen to systems, and causing an odour nuisance and negative impacts on biodiversity in both terrestrial and aquatic environments. Because it is soluble and reactive, it tends to be deposited quite quickly, and the effects are particularly damaging to vegetation close to major sources (Maier *et al*. 2008). In 2007, 91% of UK ammonia emissions were from agriculture (Defra 2010b). Emissions arise predominately from livestock housing and from the spreading of animal manure—each accounting for around a quarter of the total from agriculture—and the majority are associated with cattle. Inorganic nitrogen fertilisers account for around 12% of the total from agriculture. Urea fertiliser, in particular, is associated with much greater ammonia emissions than other fertiliser types, and the relative proportion of urea to total fertiliser applied (largely influenced by relative costs) is responsible for much of the year-to-year variability in soil emissions (Defra 2010b). The total emissions of ammonia for 2007 are estimated at 0.29 Mt, compared to the 1990 estimate of 0.36 Mt, representing a 21% reduction, primarily due to declining livestock numbers, especially cattle and pigs (Jackson *et al*. 2009), and reduced fertiliser use (Defra 2010b).

Diffuse pollution to watercourses. From a European perspective, diffuse pollution from agricultural land remains the biggest threat to recreational waters through reductions in water quality caused by contaminated runoff water. Contaminants include nitrogen, phosphorus, sediments and pesticides, as well as parasites that impact on human health (McIntyre *et al*. 2009; Section 7.3.1.2). As reported in Chapter 9, there has been a major improvement in lowland river quality over the past two decades, with chemical and biological classification of several rivers being improved between 1990 and 2008. Yet this is thought to reflect improvements in waste water treatment more than changes in agricultural practice. There has been some overall improvement in chemical river quality in Northern Ireland since 2003; however, biological river quality has deteriorated (DARD 2010).

In Enclosed Farmland, nitrogen compounds are removed through the harvesting of crops, and so need to be replaced. However, they are not used by plants with perfect efficiency, it is not always practical to apply them at the correct levels at the correct time, and economic agricultural production entails adding more nitrogen than the plants actually require, albeit at levels that are declining nationally (Section 7.2.2.4). Excess nitrogen compounds from fertilisers, manures or any other sources may be released as nitrate leaching to ground and surface waters, may contribute to soil acidification, or may be released as atmospheric emissions of ammonia, nitrous oxide and methane. Agriculture accounts for about 60% of nitrates in rivers (Hunt *et al*. 2004) and, consequently, influences coastal water quality and fisheries (EEA 2001). The increasing levels of soil fertility in and around Enclosed Farmland are associated with the rising trend of lowland vegetation becoming more homogenous and typical of higher nutrient status (Smart *et al*. 2006b; Firbank *et al*. 2008). Although nitrate concentration increased in almost 4,000 km of lowland rivers in England and Wales between 1995 and 2008, nitrate levels in English rivers have fallen overall since 2000 (despite an increase in 2004), reflecting a decrease in fertiliser use (Defra 2010a; **Figure 7.11a**). The proportion of river length with nitrate levels greater than 30 mg nitrate per litre is low in Northern Ireland, Wales and Scotland compared to England (DARD 2010).

Agriculture is also a major source of phosphorus, the primary nutrient responsible for eutrophication in freshwater (Jarvie *et al*. 2010), affecting the ecological balance of the aquatic environment and leading to changes in animal community structure (Maier *et al*. 2008; Jarvie *et al*. 2010; Chapter 9). Phosphorus from fertilisers tends to bind with soil particles, so sediment loss is associated with elevated phosphorus concentrations in waters and accounts for around 29% of phosphates in rivers (White & Hammond 2006; DARD 2010). Jarvie *et al*. (2010) reported diffuse sources of phosphorus contributing more than 90% of total load across three differing agricultural catchments. Dudley and May (2007) suggest as much as 20% of the phosphorus load in a rural catchment may be derived from septic tanks, and losses from sewage treatment works may well be responsible for continued elevated phosphorus levels in many waters (Jarvie *et al*. 2008a,b; Withers *et al*. 2009). Sediment and phosphorus loads are generally higher under arable systems than grassland ones, although pathways are highly site-specific and grassland loads can be high where grazing pressure is intense or there are additional inputs of phosphorus from manure (Watson & Foy 2001). Sediment fluxes depend on land use history and weather variability; over the past 40 to 100 years, they have tended to increase in the most intensively managed catchments but have recently fallen (**Figure 7.11b**).

Environmental risks caused by agricultural pesticides reaching watercourses from Enclosed Farmland are now very low (Chapter 9). In England and Wales, 10.1% of river length is at risk, or probably at risk, from agricultural pesticides and sheep dip, but these areas are concentrated in the uplands, rather than in Enclosed Farmland (Environment Agency 2011).

Diffuse pollution can be managed using many different approaches according to location, farming system and resources available. For example, precision farming techniques can be used to target inputs and reduce waste. Minimum tillage can reduce the transport of sediment and associated phosphorus to water via surface runoff, relative to conventional ploughing (SOWAP 2007; Deasy *et al*. 2008). Strategically sited grass buffer strips can also reduce overland sediment and nutrient runoff to watercourses (Borin *et al*. 2004), though the sediment can still sometimes be flushed out in large storm events. Field edge detention ponds can be used to trap phosphorus lost from field drains (Stoate *et al.* 2006), while ditches also reduce the impacts of agricultural pollutants on watercourses (Herzon & Helenius 2008). While it is possible, in principle, to consider which measures are most cost-effective, we lack the data that takes into account how different measures can interact at the catchment scale (Haygarth *et al.* 2009).

Anaerobic digestion and composting. Enclosed Farmland can provide waste breakdown services if the farmer imports waste biological material for anaerobic digestion or composting. Anaerobic digestion is widely used in Germany and Austria, and uptake is increasing in the UK. Agricultural manures, domestic organic waste materials and crops such as maize are digested in a vat to produce methane for use as an energy source; digestates that can be returned to the land to enhance soil organic matter, carbon and, potentially, industrial feedstocks, depending on the substrate and conditions in the digester (Banks *et al.* 2009).

7.3.2.3 Pollination

Many of the UK's field crops (e.g. oilseed rape, field beans, linseed), top fruits (e.g. apples, pears, plums), soft fruits (e.g. strawberries, raspberries, blackcurrants) and vegetables (e.g. tomatoes and peas) are dependent, at least in part, on insect pollination (Free 1993). Pollinator-dependent crops covered 20% of the UK's cropped area in 2007 (England: 23%; Northern Ireland: 5%; Scotland: 8%; Wales: unknown), and this area has increased by 41% since 1989 (Defra 2009a; Basic Horticultural Statistics 1999, 2008). Pollinators also support uncropped biodiversity by mediating seed and fruit set of many plants which feed invertebrates, birds and mammals (Jacobs *et al.* 2009).

Pollination is provided by managed honey bees (*Apis mellifera*) and a wide range of wild insect species including bumblebees, solitary bees, hoverflies, butterflies and moths. Between 1985 and 2005, honey bee colonies severely declined in number: in England, they dropped by 54%; in Northern Ireland declines are unknown; in Scotland they declined by 15%; and in Wales by 23% (Potts *et al.* 2010a). Wild bees and hoverflies are also in serious decline, with more than half of UK landscapes studied showing a significant loss of bee diversity (Biesmeijer *et al.* 2006). These declines in our pollinators have multiple causes, but a key driver is the loss of flower-rich, semi-natural landscape elements in farmland (Tscharntke *et al.* 2005; Winfree *et al.* 2009; Le Féon *et al.* 2010) such as flower-rich field margins, species-rich meadows and arable plants in crops. The loss of grass and clover leys, and the legumes they contain, has also been important (Carvell *et al.* 2006), and pesticides have been shown to have lethal and sub-lethal effects on bees (Morandin *et al.* 2005), resulting in local losses in bee diversity (Brittain *et al.* 2010).

The impacts of declines in pollinators on food production are not known. Yet the presence of semi-natural features in the landscape provides an ongoing supply of nectar and pollen which can maintain and increase crop pollination services (Kremen *et al.* 2007; Ockinger & Smith 2007; Ricketts *et al.* 2008). Several studies suggest that proximity to 'natural habitat' can influence crop pollination by native bees (Ricketts *et al.* 2008).

Pollination can be enhanced by providing high quality bee habitat such as flower-rich field margins in arable (Carvell *et al.* 2007) and grassland systems (Potts *et al.* 2009); such habitat management is supported by agri-environment schemes.

7.3.2.4 Biological pest control

Biological pest control is provided by a wide range of invertebrate predators and parasitoids, such as carabids, spiders and ladybirds (Collins *et al.* 2002; Schmidt *et al.* 2003), but it is extremely difficult to demonstrate causal relationships between such enhancement and increased food production. This is because it is not possible to establish the ideal experimental comparisons at the scale of whole fields and landscapes. In addition, natural enemies tend to be best at keeping pest populations at low levels, rather than at controlling major pest outbreaks. There is good evidence of habitat enhancement within crop fields, such as the upkeep of grass field margins, having positive effects on the abundance of natural enemies of many pest species (Landis *et al.* 2000; Collins *et al.* 2003). Yet little is known about trends in national populations of these invertebrates.

7.3.3 Supporting Services

The major supporting services provided by Enclosed Farmland include soil formation, nutrient cycling and primary production (Chapter 13). These all contribute to provisioning services described in Section 7.3.1, and also to

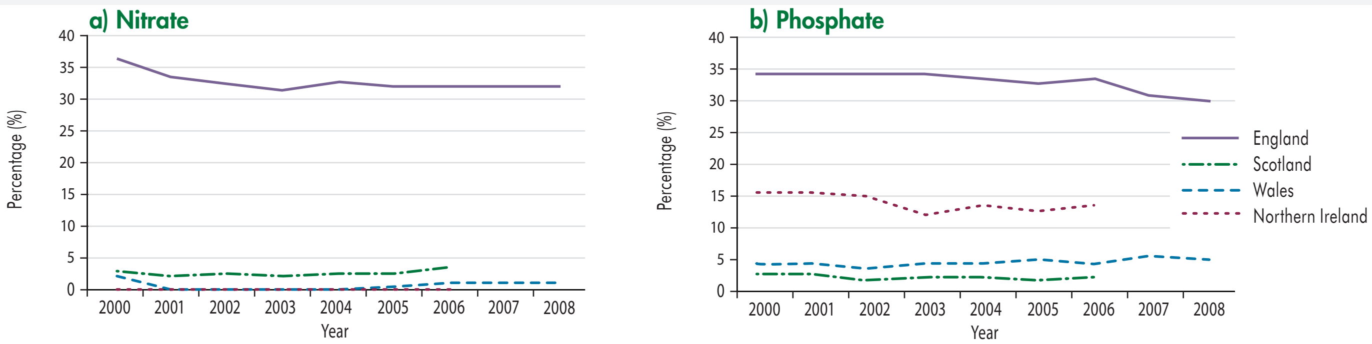

Figure 7.11 Percentage of river lengths in England, Scotland, Wales and Northern Ireland with high levels of a) nitrate (NO_3*; levels greater than 30 mg NO_3/l) and b) phosphate (P; levels greater than 0.1mg P/l) from 2000 to 2008. * Note: no values for Northern Ireland exceeded zero. Source: Defra (2010a) © Crown copyright.

some of the regulating services described in Section 7.3.2, and so are not considered separately here.

7.3.4 Cultural Services

The Enclosed Farmland of the UK is characterised by a diversity of scenery and habitat which is influenced, and valued, by many people and institutions. Enclosed Farmland provides cultural services (environmental settings; Chapter 16) to those people who live and work within it, to those who make journeys to it, and to those who enjoy less direct interactions with it, such as through reading, art, television, or by purchasing goods and services that have some form of positive association with conserving lowland farming landscapes. It can play an important role in providing contacts with nature and the living world for those who can not, or do not wish to, travel to more remote locations (Harrison *et al.* 1987; Crouch & Lubbren 2003). Here, we treat different kinds of services separately, but in practice the benefits they bring to people are often highly interactive.

7.3.4.1 Employment

Mechanisation and the economies of scale have impacted on the number of people working in agriculture, which declined from about 4 million in 1850 to around 1 million in the 1950s and 1960s (5% of the workforce); now, there are only 470,000 agricultural workers, fewer than 2% of the total UK workforce (Defra 2010a). Horticulture employs over 95,000 people (The Smith Institute 2009). The workforce for the agri-food sector as a whole is much higher at 3.6 million people, or 13.7% of the UK workforce (Defra 2010a).

7.3.4.2 Sense of place and aesthetics

The degree to which agricultural landscapes provide meaningful places for individuals varies greatly according to the nature of the landscape itself, its accessibility and the variation in values, attitudes and behaviours of individuals. In the UK, the defining sense of place appears to be built around typically rural landscapes (Weiner 2004), although preferences vary across the country. In Scotland, for example, the landscape and habitats of the Highlands provide the popular national identity. In Wales, an urban, industrial and largely English-speaking identity prevails in the south, but a rural, agricultural and Welsh-speaking one dominates in the north.

Enclosed Farmland landscapes are more important for the English sense of place. The English value the notion of 'deep England' (Matless 1998), with lowland agricultural landscapes symbolising continuity, social stability and a productive nature (Lowenthal 1991).

A recent report (Natural England 2009b) concluded that: "grassland was regarded as a flatland, which (on the whole) was not regarded as a highly interesting type of landscape. However, if people thought of it as a wild untouched meadow with wild flowers, then it was considered to be very beautiful and inspirational for painters." Indeed, while the term 'grassland' was associated with low delivery of cultural services relating to history, sense of place, leisure and spirituality, 'field systems' were generally highly valued and were felt by the same people to have worth for a sense of history, place and calm. Within 'field systems', small, irregular field systems, such as those of traditional pastoral (grassland) landscapes, were valued more highly than large arable fields; such systems also tend to be rich in biodiversity (Benton *et al*. 2003; Section 7.3.5). For many, hedgerows are quintessential and locally distinctive features which reflect cultural history, conserve outlines of past land use and define many rural landscapes. An improved knowledge of land use history enhances a sense of place and ownership of current environmental problems and opportunities (Stoate 2010).

In 2002–2003, the English Leisure Day Visits survey found that 25% of British adults had visited National Parks over the last 12 months and 7% had visited an Area of Outstanding Natural Beauty (AONB). Across the UK, there there are 49 AONBs and 14 National Parks. Although many of these are associated with open upland or coastal landscapes, a large proportion contain areas of Enclosed Farmland, while much of the character of the remainder comes from their Enclosed Farmland and mixture of crops, grass, hedgerows and woodlands (for example, the Cotswolds AONB and South Downs National Park). In England, the Enclosed Farmland at the edges of larger cities is protected from urban development by its designation of 'Green Belt land' which, in 2009, was estimated to be about 13% of the land area (Commission for Rural Communities 2008).

Traditional farm buildings provide a wide range of cultural benefits across all but the most remote landscapes of England (Gaskell & Owen 2005; Countryside Agency 2006). They provide an essential contribution to local character and to the sense-of-place enjoyed by rural communities and visitors alike, especially in certain areas such as the Cotswolds and Yorkshire Dales. They are critical to our understanding of settlement patterns and the development of the countryside. They tell us much about how our ancestors farmed and lived, and represent a historical investment in materials and energy that can be sustained through conservation and careful reuse. They are repositories of local crafts, skills and techniques, and were built using traditional materials (often closely related to the local geology) that are sometimes not available or too expensive for new building projects. They can also alleviate pressure to build on green-field land and reduce the demand for new buildings. They provide economic assets for farm and rural businesses. Some provide habitats for wildlife, particularly more generalist and common species.

Some farmland taxa have strong cultural importance and particular resonance with the public, given their widespread distribution and proximity to settlements (Mabey 1997; Donald 2004; Crocker & Mabey 2005). Examples include skylarks (*Alauda arvensis*) and other songbirds, butterflies and hedgerow flowers. One expression of this appeal is the mass participation in volunteer surveys such as the Breeding Bird Survey, Butterfly Monitoring scheme and Moths Count scheme (Defra 2009b).

7.3.4.3 Leisure

There are around 188,700 km of public rights of way in England, much of which crosses Enclosed Farmland; 78% are public footpaths giving a right of way on foot; 17% are bridleways giving access to pedestrians, horse riders and cyclists; and 5% are restricted byways along which vehicles may travel (Commission for Rural Communities 2008). According to Natural England's 2005 English Leisure Visits Survey, approximately one third of visits were to the countryside, with coast and woodlands the most favoured destinations. The duration of the visits was split equally between more than and less than three hours, with nearly 60% using a car and 25% walking, suggesting that there is likely to be a fairly even division between visits to meaningful local places and visits to socially valued landscapes. More than 184,000 people attended events on 420 farms for Linking Environment and Farming (LEAF)'s Open Farm Sunday in 2010. In 2006, it was estimated that there were around 1 million horses in the UK, and 4.4 million people (or 7% of the GB population) had ridden horses in the previous 12 months. Of these, 1.1 million are estimated to be 'regular riders' (Commission for Rural Communities 2008). It is not clear how much Enclosed Farmland is being managed primarily for horses and other leisure uses.

Game shooting is widely associated with lowland farmland, which is modified to meet the requirements of (mainly) released non-native pheasants and red-legged partridges (Dickson *et al.* 2009). Around 370,000 people regularly shoot game in England and this activity supported around 54,000 full-time equivalent jobs and influenced the management of over 8.5 million ha of countryside (PACEC 2006). Twenty-two percent of shoots are operated as businesses (PACEC 2006), but, in a wider sense, shooting is an economic activity involving the purchase of poults for releasing, the trade in shot game, and other employment associated directly or indirectly with the shoot.

7.3.4.4 Human health

Enclosed Farmland provides a vital health benefit to the UK's population by providing safe, nutritious food; UK foodstuffs are monitored to ensure pesticide residues are kept well below safety levels. Enclosed Farmland also provides health benefits associated with exercise and recreation in the countryside (Barton & Pretty 2010). Moreover, living in the countryside reduces inequalities in death rates between rich and poor (Mitchell & Popham 2008). Health risks from Enclosed Farmland are greatest from mechanical injury to the workforce, but primary airborne particulates arising from intensive livestock housing and field operations can cause human respiratory problems (Foley *et al.* 2005). Opponents of GM crops have raised the issue of health risks to people, but there are no examples of human health being affected by exposure to these crops.

Health risks arise to users of bathing water from parasites found in livestock faeces, such as *Escherichia coli 0157:H7* (FAO 2006) and *Cryptosporidium* (Patz *et al.* 2004), being transported by surface water into ditches, streams and rivers. In practice, it is hard to distinguish between microbial pollution arising from agricultural diffuse and domestic point sources, in particular, septic tanks (Neal *et al.* 2010). As well as affecting water quality in the immediate vicinity of the septic tank and downstream, such pollution may have implications for marine water quality and the associated bathing areas and shellfish industry (Harris 1995; Geary & Davies 2003). In addition to generic faecal coloniforms, the microorganisms discharged from septic tank effluents may include pathogenic types, such as *Salmonella* species, various *E. coli* and *Enterococcus* species (Harris *et al.* 1995; Geary & Davies 2003), and enteric viruses (Scandura & Sobsey 1997). To date, no human infections within the UK have been directly linked to pathogens from septic tanks, although such links have been proven elsewhere. The majority of septic tank systems in agricultural catchments are thought to be old and the costs of retrospective fitting of treatments systems (Harrison *et al.* 2000; Tanner *et al.* 2002) could prove prohibitive.

Other risks to human health include releases of antibiotics and sediments from eroded pastures (Fewtrell *et al.* 2005; FAO 2006); however, the emergence of antibiotic resistance in the UK is unlikely as antibiotics are not allowed as growth promotors. For more detail on disease regulation see Chapter 14, Tables 14.9–14.11.

7.3.5 Wild Species Diversity

Enclosed Farmland is associated with a suite of species favoured by habitats that are early successional, open, disturbed and/or in ecotones and mosaics with woodland. It is home to both specialist and generalist plants and animals, which contribute in various ways to provisioning, regulating, cultural and supporting services (see Section 7.3), although quantitative data are usually lacking on the values and benefits they provide. Arable specialists are typically associated with relatively stable, early successional conditions; for example, many of the UK's rarest plants are associated with long-term cereal agriculture. Species-rich grasslands in farmed landscapes are addressed in Chapter 6.

In agricultural landscapes, biodiversity is greatest where there is heterogeniety of habitats over multiple scales of space and time (Benton *et al.* 2003). This is because such landscapes provide a range of ecological niches, turnover of habitats for those species that require it, the possibility of dispersal between habitats, and conditions for those species that require more than one habitat. Most species that are regarded as emblematic of high quality countryside, such as songbirds, butterflies and hedgerow flowers, are adapted to such complex mosaics. Farming systems that promote such diversity, notably organic, tend to support such species in greater abundance per unit area (Fuller *et al.* 2005).

The Enclosed Farmland UK NEA Broad Habitat contains two Biodiversity Action Plan (BAP) habitats, namely arable field margins and hedgerows. In turn, these include BAP priority species (65 and 83 in the two habitats, respectively) such as pheasant's-eye (*Adonis annua*), grey partridge and brown hare (*Lepus europaeus*). Hedgerows provide primary habitat for 13 globally threatened or rapidly declining species and, where they are ancient or remnants of ancient woodland, may act as refuges for characteristic woodland plants and ancient trees. Although they are often small in area, long-established farm woodlands may have high conservation value, especially if they are ancient woodland (Goldberg *et al.* 2007). Farm ponds contribute considerably to the biodiversity of agricultural ecosystems, supporting more species, more unique species and more scarce species than other types of waterbody (Williams *et al.* 2004). Ditches (most of which are seasonal) are the least species-rich aquatic habitat associated with farmland, but support uncommon species, including temporary water invertebrates not recorded in other waterbody types (Williams *et al.* 2004)

Declines in species diversity and abundance. Changes in agricultural practices must have always resulted in population ebbs and flows according to which species were best suited to the prevailing land management regimes (Stoate 1995, 1996; Shrubb 2003). But changes in Enclosed Farmland during the 20th Century changed the balance between provisioning of food and biodiversity. The result has been major declines in the diversity and numbers of plants, terrestrial invertebrates and vertebrates (Potts 1986; Rich & Woodruff 1996; Ewald & Aebisher 1999; Chamberlain *et al.* 2000; Robinson & Sutherland 2002; Holloway 2002; Shrubb 2003; Wilson *et al.* 2009). It is hard to quantify long-term declines, given that they started well before biological recording systems had been established, but indications of trends can be seen from wild game counts (Tapper 1999), biodiversity on traditionally managed areas, such as hay meadows and some plots in the Rothamsted classic experiments, and from archaeological records.

The majority of agricultural grassland is now species-poor and structurally uniform (Wilson *et al.* 2005) because of greater fertiliser inputs (Firbank *et al.* 2008), increased stocking levels and a switch from hay-making to silage production (Chamberlain *et al.* 2000; Petit & Elbersen 2006). While most species-rich grassland had been lost by the 1980s (Fuller 1987), the process of species loss continued until 1998, with no significant change detected between 1998 and 2007 (Carey *et al.* 2008). These trends do, however, vary nationally; for example, plant species richness in Scottish Improved Grasslands declined by 7% between 1998 and 2007 (Norton *et al.* 2009a).

Similarly, the use of fertilisers, selective herbicides and the switch from spring-sown to autumn-sown cereals has impacted on the arable flora. Many broadleaved arable plants declined markedly between 1960 and 2000 (Preston *et al.* 2002), and probably before; arable plants now comprise the most nationally threatened element of the UK's flora. By contrast, there have been increases in some competitive grass plants that are less sensitive to herbicide control in cereals and are better suited to autumn-sown crops (e.g. blackgrass, *Alopecurus myosuroides*). Plant species diversity and abundance now tend to be higher at field margins (Marshall *et al.* 2003) and in those relatively few fields where management has not been so intensive (Watkinson *et al.* 2000).

The flora of field boundaries has also changed, with increases in plants that are competitive and have high nutrient requirements, and decreases in plants that are important food resources for pollinators and farmland birds. This has been largely driven by the increasing nutrient status of Enclosed Farmland (Smart *et al.* 2000). Other possible causes include changes in management and drift of pesticides, although this is not considered a major problem with modern methods of spraying (Roy *et al.* 2003). Plant species diversity in grassland has become largely confined to field edges (Smart *et al.* 2002, 2006c; Walker *et al.* 2009) as these areas have been impacted less by these changes.

Changes in the plant composition of Enclosed Farmland have inevitably impacted species higher up the ecological food chain (**Box 7.2**). Within arable fields, numbers of invertebrates at higher trophic levels are related to numbers of foodplants (Hawes *et al.* 2003). There is evidence of

Box 7.2 The Sussex Study: a long-term study of a farmland ecosystem.

In the late 1960s, a national decline in numbers of grey partridges (*Perdix perdix*) was causing concern, so a programme of research and monitoring was set up in Sussex to elucidate what was happening, and has continued uninterrupted ever since (Potts *et al.* 2010b). Grey partridges and other wildlife, especially insects, have been monitored by the Game & Wildlife Conservation Trust on 12 farms across the South Downs between Arundel and Worthing. Forming the first ever study of the wildlife associated with cereal farming, results revealed that the decline of the grey partridge in the 1960s was a consequence of a fall in chick survival rate caused by a shortage of insects in the chicks' diet during the first two weeks after hatching. As a result, from 1970 onwards, information regarding grey partridge abundance and productivity, crop types, invertebrate densities and overall weed abundance has been collected from 32 km^2 in June and September every year using the same methods. Pesticide data is also available for most farms. Thus this 40-year study is the longest of its type anywhere in the world and spans some substantial changes in agriculture including the introduction and widespread use of insecticides and fungicides, the switch from spring to autumn sowing of cereals and the decline of mixed farming (arable and livestock).

Early findings from the study were instrumental in highlighting the indirect effects of pesticide use, in particular, the effects of herbicides. The removal of weeds through herbicide use led to a reduction in the abundance of insects, especially those that feed on weeds. This disrupted the food chain on which grey partridge productivity depended. Consequently, the Sussex Study is considered to have accumulated the best and most continuous evidence for the indirect effects of pesticides on farmland birds. Over the duration of the project, the overall abundance of invertebrates has declined by 43%. The decline was steepest between 1970 and 1985, but there has since been some recovery. Of these invertebrates, the fungus-feeding species have declined by 77% and the predators and parasites by 47%.

The Sussex Downs are recognised as one of the hot spots for rare arable plants and 171 species have been identified in the project area. Although the total number of weed species has remained stable over the last 40 years, 19 species have been lost or become very rare, while 18 species have been added. Analysis of herbicide data has revealed that the timing of their use is important, with spring herbicide applications being most damaging to the arable flora, and, in turn, having the greatest effect on the abundance of insects and the subsequent productivity of grey partridge.

Long-term study site of farmland in Sussex. Initial work on invertebrates and arable flora on this study site led to conservation headlands (in foreground). *Photo courtesy of Peter Thompson / Game & Wildlife Conservation Trust.*

declines in pollinators (Section 7.3.2.3.) and aerial insects occurring over several decades, though not in all locations (Benton *et al.* 2002; Shortall *et al.* 2009).

Reductions in safe nest sites, invertebrates during the breeding season and in seed resources in the autumn and winter have resulted in major reductions in numbers of farmland birds (Chamberlain *et al.* 2000; Krebs *et al.* 1999; Boatman *et al.* 2004). Between the start of the time-series of annual bird surveys in the 1970s and the early 1990s, the UK population of farmland birds almost halved, remaining relatively stable ever since (**Figure 7.12**). There is some variation in pattern between the four UK countries; for instance, numbers have been essentially stable in Scotland. With regards to species trends, populations of farmland generalists, including corvids and pigeons, have remained around or above the 1970 level. However, those specialist species that rely on plants and invertebrates of Enclosed Farmland, such as grey partridge and corn bunting (*Emberiza calandra*) have continued to decline and numbers are now about a third of what they were in 1970 (**Figure 7.12**).

In grasslands, birds have been directly affected by the reduction in botanic species richness and subsequent declines in weed seeds and key invertebrate prey (Woodcock *et al.* 2009). They have also been indirectly affected by other changes in field management (Vickery *et al.* 2001) including: increased defoliation pressure from both silage-cropping and grazing removing seeds and sward-dwelling invertebrate prey (Buckingham *et al.* 2006); earlier and more frequent mowing of forage grass impacting breeding productivity of ground-nesting birds (Wilson *et al.* 2007); poor access in crops made dense and tall by high nutrient inputs (Wilson *et al.* 2005); and changes in soil drainage and soil structure impacting on soil invertebrate prey availability (Peach *et al.* 2004; Smart *et al.* 2006a).

Landscape simplification is an important mechanism of biodiversity loss from Enclosed Farmland (Robinson & Sutherland 2002; Firbank *et al.* 2008). More complex agricultural landscapes support a greater diversity of species (Benton *et al.* 2003; Fuller *et al.* 2005; Firbank *et al.* 2008), partly because of the amounts of habitat, partly due to the fact that several species of conservation concern require spatial and temporal variation in land cover (Bignal & McCracken 2000) (e.g. breeding lapwings, *Vanellus vanellus*, require cover and more open ground for feeding, while bats tend to hunt along hedgerows), and partly because other species need to disperse between features such as ponds or woodlands (e.g. amphibia, nuthatches *Sitta europaea*). For example, the extent of arable land in the crofting area of the Western Isles has declined to about 230 ha, with concomitant declines in birds and plants associated with crops (SNH 2009).

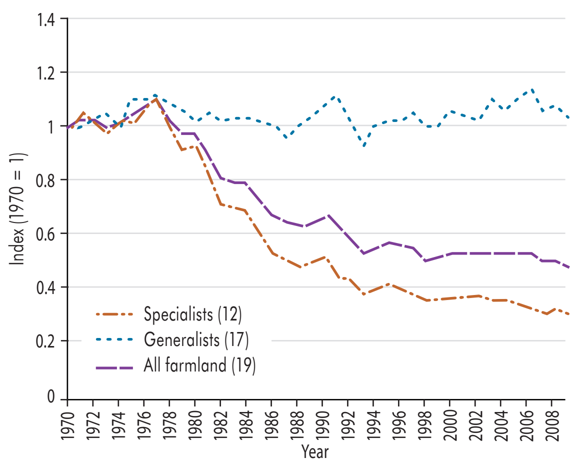

Figure 7.12 Populations of UK farmland birds, 1970 to 2009. Figures in brackets show the number of species. Source: data from RSPB; BTO; Defra (2011).

Another way of looking at trends in biodiversity of Enclosed Farmland is to look at the condition of sites designated for conservation, i.e. Sites of Special Scientific Interest (SSSIs) in GB and Areas of Special Scientific Interest in Northern Ireland (ASSIs). Across the UK as a whole, in 2006, Arable Horticultural sites and Improved Grasslands were in the worst condition of any habitats, even compared with other agricultural habitats, with only 26 out of 710 in favourable condition, and 536 unfavourable or destroyed (Defra 2009c).

Restoration of biodiversity. The past 20 years has seen the development of several techniques for increasing biodiversity and leisure services in Enclosed Farmland. They include bare patches in fields for nesting skylarks (Morris 2007), game cover for granivorous birds (Stoate *et al.* 2004; Parish & Sotherton 2008), flower mixes that provide pollen and nectar for foraging bumblebees (Carvell *et al.* 2007), beetle banks to support generalist predators (Collins *et al.* 2003), and conservation headlands (Sotherton 1991) to support grey partridge and associated taxa. Such management for biodiversity has been embraced within BAPs, and is often funded through agri-environment and similar schemes. There is a great deal of voluntary action: 92% of farmers in England have hedges on their farm, 82% of farmers cut their hedges at specific times (October–March) to avoid harming nesting birds and 53% of cereal farmers have used beetle banks or field margin management to encourage natural predators (Defra 2008).

Recent trends in species diversity and abundance. During the 1990s, there were changes to the management of Enclosed Farmland that were expected to benefit biodiversity. These included set-aside, agri-environment schemes, cross compliance, the application of technology to improve the efficiency of fertiliser and pesticide applications, the restoration of habitat features such as field boundaries and hedgerows under BAPs, and an increasing awareness of the cultural value of biodiversity by the agricultural and food chain industries.

It is difficult to detect impacts on wild species associated with Enclosed Farmland, given that high quality, national data is collected on an annual basis for only a few groups (e.g. birds, butterflies), it is not always easy to separate out species which are wholly Enclosed Farmland-specific, and that there are likely to be time lags before species show a response. Nevertheless, it seems that some population declines have been halted, if not reversed. At the UK level, overall plant species richness in arable habitats increased between 1990 and 2007, after showing a decline between 1978 and 1990 (Carey *et al.* 2008), while the numbers of farmland bird and butterfly foodplant species in arable fields increased by 22% and 24%, respectively, between 1998 and 2007 (these trends were most evident in England, with the situation in Scotland and Wales remaining stable from 1990) (Carey *et al.* 2008). However, while the proportion of ground covered by common plant species used as food by butterflies or birds has increased in arable land at the UK level, it was still less than 1% of the cropped land between 1998 and 2007 (Carey *et al.* 2008).

7.4 Trade-offs and Synergies Among Enclosed Farmland Goods and Services

Agricultural production is essentially an extractive service: plant cover and soils are frequently disturbed; community structure is highly manipulated to favour some species at the expense of others; plant and animal production is removed from the system; and lost nutrients are reintroduced using organic and inorganic fertilisers that are not taken up with perfect efficiency. These properties all tend to create conflicts with those ecosystem services that are best delivered by ecosystems subject to much less intervention (Henle *et al.* 2008); such conflicts become increasingly hard to avoid at higher intensities and volumes of production.

Pilgrim *et al.* (2010) looked at the interactions among the delivery of ecosystem services from European temperate grasslands, namely agricultural production, climate regulation, air quality regulation, water quality regulation, hydrological regulation, soil erosion regulation, nutrient cycling, biodiversity conservation and landscape quality. Of the 72 direct pair-wise interactions studied, 37 were positive and 21 were inconclusive (**Figure 7.13**). All six negative relationships arose from the effects of agricultural production as a driving force on the delivery of other ecosystem services, with consistent evidence of negative impacts on air quality, water quality, erosion regulation, nutrient cycling, biodiversity conservation and landscape quality. Of all the potential driving ecosystem services, only erosion regulation and efficient nutrient cycling were consistently reported to enhance agricultural production. By contrast, interactions among the non-agricultural production ecosystem services tend to be positive or the evidence is currently inconclusive.

The situation in arable systems may well be different. In

Driving Factor \ Responding Factor	Agricultural production	Climate regulation	Air quality	Water quality	Hydrological regulation	Erosion regulation	Nutrient cycling	Biodiversity conservation	Landscape quality
Agricultural production		↕ ***	↓ ***	↓ ***	↕ **	↓ **	↓ ***	↓ ***	↓ ***
Climate regulation	↕ **		↑***	↑***	↑ **	↑ **	↕ **	↕ **	↕ **
Air quality	↕ **	↕ **		↑ ***	↑ *	0	↑ **	↑ ***	↑ ***
Water quality	↔	↕ **	↕ **		↕ **	0	0	↑ **	↑ **
Hydrological regulation	↕ **	↕ **	↔	↑ **		0	↑ ***	↑ **	↑ **
Erosion regulation	↑ **	↕ **	↑ **	↑ ***	↑ *		↕ **	↑ **	↔
Nutrient cycling	↑ ***	↑ **	↑ *	↑ ***	↑ **	↑ *		↑ **	↑ **
Biodiversity conservation	↕ **	↕ **	↔	↑ **	↑ **	↑ **	↑ *		↑ ***
Landscape quality	↕ *	↕ *	↕ *	↑ *	↑ *	↑ **	↕ **	↑ ***	

Figure 7.13 The relationship between the ecosystem service A (ES A) as a driving factor and ecosystem service B (ES B) as a responding factor in grasslands in North West Europe. The form of the relationship is given by the arrows: 0 = no direct relationship, ↓ = decline in ES B, ↑ = an increase in ES B, ↕ = evidence of the relationship between ES A and ES B is divided or inconclusive, ↔ = no current evidence in the literature of an interaction between ES A and ES B. The strength of the relationship between ES A and ES B is reflected in the number of stars ***= highly confident about evidence **= mixed confidence about evidence *= poor confidence in evidence. Cell colour reflects scenario type: ▢: win-win; ▢: lose-lose; ▢: variable outcome; ▢ no known interaction. Pilgrim *et al.* (2010). Copyright (2010), reproduced with permission from Elsevier.

particular, the regulating services of biological pest control and pollination are enhanced through the provision of habitat features that benefit other taxa, implying a win-win between provisioning of food and at least some other ecosystem services. Yet critically, we are not aware of any solid evidence showing an increase in food production in the UK following the introduction of such features. The extent to which these services can be substituted by the use of domestic honey bees and the use of cultural and chemical pest control measures is not known, but likely to be high given that national levels of food production have increased as biodiversity has declined.

7.5 Options for Sustainable Management

It is envisaged that the global demands for agricultural production of food, energy and materials will increase greatly in the coming decades as a result of increased UK and global population and changing diets; during this time, the potential costs of key inputs of water, nutrients and energy are likely to rise. Other ecosystem services from Enclosed Farmland are becoming more valued and controlled through regulation, subsidy and markets. It is also envisaged that climate change will introduce increased uncertainty and risk to ecosystem service delivery. Therefore, UK agriculture needs to become more productive in terms of food and energy (so it does not make additional demands upon agricultural habitats elsewhere), more efficient in terms of resource utilisation, more productive in terms of other ecosystem services, and more resilient to climate and other changes; such alterations must be sustainable over time.

7.5.1 Increasing Food and Energy Production

To increase the provisioning of food and bioenergy, productivity per unit area must be intensified and/or the area of production must be expanded. The area of land used for bioenergy production is likely to increase given current policy drivers. Ideally, competition with land used for food production can be reduced by using land of low agricultural value for growing bioenergy crops, or by generating bioenergy as a co-product of food production, whether by using straw as biomass or slurries for anaerobic digestion. Nevertheless, there is scope for the replacement of some areas of arable farming with biofuels. This, plus existing pressures on land use, makes it likely that the area of Enclosed Farmland available for UK food production will decrease rather than increase. Therefore, there is a need to improve provisioning of food per unit area in the UK.

There is an important role for technological developments—such as cultivating new varieties, improving the protection of crops and livestock from pests, weeds and disease, and enhancing the resilience of food production against climate change impacts—and knowledge transfer, coupled with appropriate economics to ensure the adoption of such developments (Royal Society 2009).

7.5.2 Increasing the Resource Use Efficiency of Food Production

Many of the drawbacks of agricultural production arise from the loss of nutrients from the farming system (including diffuse pollution with nitrate and phosphorus), and emission of ammonia, methane and nitrous oxide to the atmosphere. Therefore, increasing the efficiency that plants and animals use these materials will result in improved ecosystem regulation. For instance, recent reductions in fertiliser inputs and emissions to air and water are partly due to increasing resource use efficiency, as well as reduced livestock numbers.

Techniques to increase resource use efficiency are already available, but are likely to become more widespread as productivity is increasingly reported per unit of water, carbon or other resource, and as the resources themselves become more expensive. Waste can be reduced by more precise application of irrigation water and nutrients in space and time. Greenhouse gas emissions from livestock can be reduced by improving growth rates, changing diets and changing storage methods for slurries and manures. Mixed livestock and arable farming may once again make economic sense should transport costs of nutrients increase, albeit at larger scales than before. Pigs may prove more valuable than ruminants because of their ability to feed on a greater variety of protein sources and their lower levels of greenhouse gas emissions. There is also scope for more efficient use of the food that is already produced, for example, by reducing food waste throughout the food chain and reducing the proportion of arable production that is used for livestock feed.

7.5.3 The Delivery of Regulating and Cultural Services

The delivery of ecosystem services is strongly influenced by both regulation and financial support and is likely to be increasingly influenced by markets.

Regulations include the WFD, Pesticides Directive, Habitats Directive, Nitrates Directive and Landscape Directive. They tend to control different aspects of the agro-ecosystem singly, imposing spatial boundaries within which land management can operate to deliver ecosystem services. The cost-benefit of current and proposed regulations in terms of ecosystem services is rarely known. It is possible to replace some regulations with taxes, but their effectiveness depends on the detail. For example, a nitrogen tax should result in reduced diffuse pollution, but could encourage farmers to use cheaper, urea-based fertilisers resulting in increased greenhouse gas emissions.

Support measures currently include rural development and agri-environment schemes. In Scotland, CAP-based policy instruments presently have the greatest impact on land management decisions (Miller *et al.* 2009). While cross compliance and agri-environment measures have had some successes to date (Section 7.2.2.9), the cost of meeting publicly defined objectives from agri-environment schemes in the UK (including in the uplands) is estimated at just under £2 billion per year (Cao *et al.* 2009; **Table 7.6**): more than three times the funding currently available from existing CAP Rural Development Programme allocations.

Table 7.6 A breakdown of the annual cost of agri-environment scheme options to deliver environmental policy objectives across the UK (£ million). Note that a number of assumptions were made in the analyses (e.g. incentives, such as provided through agri-environment schemes, are assumed to be the primary delivery mechanism used to achieve environmental gains; and existing income-foregone calculations are used to calculate land management costs). Taken together, the overall impact of these assumptions means that the costs in the report may significantly underestimate the total funding necessary within the UK. Source: Cao *et al.* (2009).

	England	Scotland	Wales	Northern Ireland	UK	% Total
Biodiversity	624	250	72	57	1,003	**51%**
Landscape	107	86	19	9	220	**11%**
Climate change mitigation	173	37	29	31	270	**14%**
Flood risk management	43	28	14	7	92	**5%**
Farmland historic environment	9	3	2	2	15	**1%**
Soil quality	95	18	0.3	0.6	114	**6%**
Water quantity	70	*	*	*	69	**3%**
Resource protection	99	19	23	13	154	**8%**
Public access	38	4	7	0.2	48	**2%**
Total (£ million)	**1,258**	**444**	**165**	**119**	**1,986**	
% Total	**63%**	**22%**	**8%**	**6%**		

*Indicator currently only applies to England but may extend to other regions by 2020 due to climate change; additionally, actions may be given priority in terms of resource efficiency.

It is not always clear that scheme resources are being targeted in the most effective way. Payments are often on the basis of actions by the farmer; thus the new Welsh Glastir scheme will make payments according to a national points system for different management actions, each intended to have some form of environmental benefit. Such payments assume that the prescriptions are correct, yet the evidence for prescriptions is variable in quality, the added value of combinations of actions is not well understood, and there may be local variations in efficacy that could be dealt with by a more flexible approach than rigid prescriptions allow. However, while it may seem to make sense to pay farmers by results (Schwarz *et al.* 2009), and to prioritise according to the local environmental context, the increased costs and complexity of scheme management may not be worthwhile.

There are two kinds of market support for ecosystem services other than food and energy production. One is direct payment, for example, for holiday accommodation in the countryside, for which there is a mature market, or for carbon sequestration, the market for which is in its infancy. Another type of support is to seek increased market share by adding value to food items. For example, Conservation Grade, the LEAF marque and organic production all have mechanisms for incorporating environmental objectives into production and marketing of food. Conservation Grade incorporates wildlife habitat into farming systems, while both LEAF and organic production assure an integrated approach to resource use and land management, the former promoting integrated and precision crop management, and the latter greatly restricting the use of inorganic fertilisers and agrochemicals. The promotion of products with added environmental value by supermarket chains is ensuring market penetration of such approaches.

7.5.4 The Joint Delivery of Food, Energy and Other Ecosystem Services

Increasing agricultural production is currently associated with reductions in other ecosystem services (Section 7.4.). But new research is showing that not all of these reductions are inevitable: there is more scope for joint production of multiple ecosystem services than has been previously realised (**Box 7.3**). For example, varieties of forage grass are being developed with roots that can improve the water-holding capacity of soils, in turn, improving water regulation on farmland. In addition, grass varieties with high sugar content are reducing methane emissions from cattle. Greenhouse gas emissions from livestock are reduced when the animals are healthy, well-nourished and grow rapidly. In arable systems, minimum tillage and no-tillage are often proposed as a key mechanism for reducing the negative impacts of cultivation on water quality, increasing carbon sequestration, improving soil function, and delivering biodiversity benefits (Holland 2004; Field *et al.* 2007a,b). However, there is evidence to suggest that carbon may be redistributed within the soil, rather than sequestered, and that nitrous oxide emissions may be increased because of low soil aeration and increased waterlogging (Bhogal *et al.* 2008).

It has been suggested that a switch to perennial crops may be beneficial for carbon sequestration and reducing diffuse pollution, as regular soil disturbance is avoided (although this may be detrimental to some arable plants). It is possible that advances in plant breeding and post-harvest processing will facilitate this in the future (Glover *et al.* 2010).

But win-win solutions may not always be possible. It is not clear to what extent UK soils can act as carbon sinks without major conversion of arable to grassland or forest, while there are clear conflicts between increased agricultural production and habitat and species diversity on the same units of land.

General rules about when to expect beneficial trade-offs among ecosystem services in agricultural landscapes are lacking (Bennett *et al.* 2009). Getting the balance right is a political issue as the values attached to different ecosystem services vary between people; it is also a scientific issue as the chosen balance requires technical knowledge to be implemented successfully. It raises the question, is it better to have reduced production and enhanced environmental quality on the same areas of land, or to have distinct units of land allocated to different functions?

This question is referred to as 'land sharing versus land sparing'. Land sharing involves the adoption of more extensive farming systems which provide multiple services from the same area, but probably with lower efficiency per unit area for given services than a more intensive approach might achieve (Balmford *et al.* 2005). Organic farming, for instance, usually has positive effects on species richness and abundance (depending on taxa and landscapes) in the order of 10% increases compared with non-organic systems. These positive effects arise largely from the greater diversity of land covers (Bengtsson *et al.* 2005, Fuller *et al.* 2005; Macfadyen *et al.* 2009). However, these advantages are per unit area, and do not take into account the reduced yield. It has been estimated that a national shift to organic-only farming could reduce UK wheat yield to about a third of current production (Jones & Crane 2009). This is because

Box 7.3 Case study 2: reconciling the provision of multiple ecosystem services on farmland.

In recent decades, much effort has been directed to reconciling the two objectives of continued production of provisioning services and biodiversity conservation. Here, we examine three examples, involving both empirical and modelling approaches, to explore how the provision of multiple ecosystem services might be achieved on UK farmland.

The first example is the RSPB's **Hope Farm**, a conventional arable farm in Cambridgeshire that shows how production and conservation can be reconciled by excluding a small proportion of the potential cropped area from food production. Hope Farm was bought by the RSPB in 1999 with many donations from RSPB members and other members of the public. The 181-hectare farm is on heavy clay, with 5 ha under permanent pasture and 7 ha of semi-natural habitats such as farm woodlands. The majority of the remainder is farmed by a contractor to grow a rotation of autumn-sown wheat, oilseed rape and spring beans. Efforts to increase farmland bird numbers have focused on Environmental Stewardship options, such as grass margins and seed-rich habitats, and good practice farming such as cutting hedgerows and ditch vegetation just once every three years. There have also been trials of management techniques for particular species, such as the provision of skylark plots. Since the baseline year in 2000, when all 169 ha of the potential cropped area was cropped, an average of 18 ha has been devoted to set-aside and non-crop features, with the latter mainly in low-yielding, field edge locations (Morris *et al.* 2010).

At Hope Farm, breeding bird numbers increased substantially between 2000 and 2009 (**Figure 1**), while farmland bird populations in the wider countryside remained steady across eastern England. This is due to increases in numbers of both common and rare (e.g. BAP) species. Changes include increased numbers of skylark (10 pairs in 2000, increasing to 44 in 2009) and yellowhammer (*Emberiza citrinella*; 16 pairs increasing to 39), and colonisation by lapwing and grey partridge (Morris *et al.* 2010). Doubling the farmland bird index has not compromised crop yields (**Figure 1**); Hope Farm has consistently exceeded the national wheat yield average, for example, the harvest in 2009 was 9.35 tonnes/hectare, compared to the national level of 7.6 tonnes/hectare (Morris *et al.* 2010).

The Game & Wildlife Conservation Trust's **Allerton Project** shows how food production can be reconciled with the provision of a wider range of cultural services. The Allerton Project is based at a 333 ha mixed arable/pastoral farm at Loddington, Leicestershire. Management practices researched and implemented for biodiversity include grass margins, beetle banks and wild bird seed crops as part of a game management system designed to increase numbers of wild gamebirds for shooting. Summer aphicides are no longer used on cereals at Loddington as sufficient control is achieved by predatory invertebrates associated with grass margins and beetle banks. The farm produces 410 to 538 lambs each year, and sheep wool and flax are sold for fibre. Wood chip is harvested from farm woods during thinning operations and provides an important source of fuel for the Project's headquarters and other local premises, reducing carbon emissions associated with the procurement, transport and use of fossil fuels.

Breeding bird numbers increased substantially at Loddington until 2001, but subsequently declined due to the cessation of some components of the game management system. As at Hope Farm, increases in bird numbers were achieved while crop yields remained consistent (**Figure 2**).

At Loddington, the provision of two other services has been quantified: recreational and educational opportunities. The farm has been managed as a recreational pheasant shoot and has a suite of associated management measures including the provision of grain in winter, the control of nest predators and the creation and management of a range of habitats (Boatman & Brockless 1998; Stoate 2002). This provided recreational opportunities for shooters, beaters and dog handlers (**Figure 2**), without compromising crop yields. In addition, the Allerton Project provides education, demonstration and knowledge exchange opportunities for policy makers, regulators, farmers, agronomists and students (Stoate 2004; **Figure 2**), as well as community engagement outside the farm boundary at the stream catchment scale (Stoate 2010).

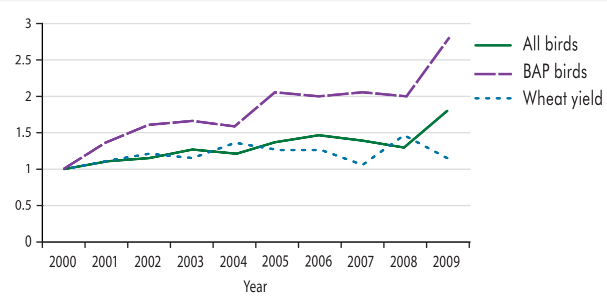

Figure 1 Trends in wheat yields and birds at Hope Farm. To enable comparison of trends, all variables are converted to an index with the value in the first year set to 1. Source: RSPB pers. comm.

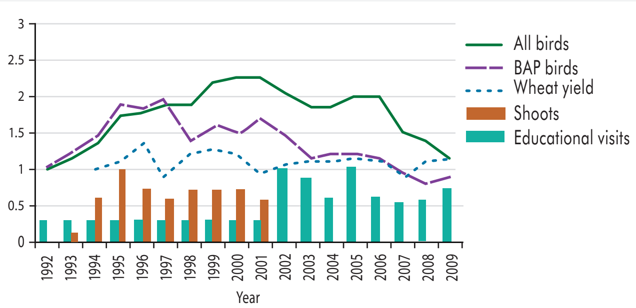

Figure 2 Trends in various services at the Allerton Project. Note that visitor numbers were not captured prior to 2001, and so are estimated prior to that year. As with Hope Farm, variables are converted to indices for ease of comparison of trends. Source: data from Game & Wildlife Conservation Trust (2010).

yields of wheat grown organically are about two-thirds of those grown conventionally with fertilisers and chemical pest and disease control, and wheat can only be grown for half of an organic rotation at most, the rest of the rotation needing legumes to restore soil fertility or root crops to control pests and diseases (Goulding *et al.* 2009). National data are not available for livestock organic yields. Extensive agriculture alone will not meet the challenge of increased joint production of food and other ecosystem services.

Land sparing, on the other hand, involves concentrating agricultural production into certain areas of land, so that other areas are available to provide other services, which need not be in the UK. The optimum solution depends on the relative productivity of both shared and distinct land units for the services of interest, and how the services are valued (Hodgson *et al.* 2010). Land sparing is only an effective strategy if the spared land actually delivers ecosystem services. Land sparing can take place at all scales, including individual patches within fields, and will depend on the landscape context (Bradbury *et al.* 2010; Hodgson *et al.* 2010). The segregation of ecosystem services need not be complete; for example, the pioneering Conservation Headlands approach developed by the Game Conservancy and Wildlife Trust (Sotherton 1991) involves reducing pesticide sprays at the less productive field edge. Conservation Headlands still produce food, but with a yield penalty that is considered to

How, though, might one attempt the reconciliation of food production with a wider range of other benefits? One approach is that taken by Posthumus *et al.* (2010) who estimated the provision of a range of ecosystem services by **The Beckingham Marshes** under the current, and various alternative, future land use scenarios (**Figure 3**).

The Beckingham Marshes consist of 900 ha of floodplain by the River Trent in Nottinghamshire. Flood defences were built in the 1960s to provide 2 million m^3 of controlled flood storage in order to reduce the probability of inundation of Gainsborough. Land drainage improvements and a new pumping station improved conditions for arable farming throughout the 1970s, so much so that, by 1983, 82% of the area was arable. In 2005, 90 ha of arable land was reverted to extensive grassland under a collaboration between the Environment Agency and the RSPB (RSPB 2009). Posthumus *et al.* (2010) used a modelling approach to compare four alternative future scenarios with the current situation:

1. Maximum agricultural production: with land under intensive arable agriculture.
2. Biodiversity: with land used to enhance local and national BAP targets.
3. Agri-environment: as (2) but with the constraint that land remains predominantly agricultural.
4. Floodwater storage: with land used to provide maximum flood water storage.

The more intensive farming system had the greatest scores for global warming potential and nitrate leaching, and the lowest scores for habitat conservation: marginally lower than the conservation value of the current land use and much lower than the biodiversity scenario. Habitat conservation value under the agri-environment scenario was marginally higher than under the biodiversity scenario, primarily due to the high nature conservation value of alluvial hay meadows. Flood risks varied between scenarios as the frequency of flooding varied: the higher the flood frequency, the higher the average annual costs of flood damage. Flood damage costs were low (in comparison to the monetary values of other indicators) under all scenarios due to the low density of infrastructure and residential homes in the floodplain.

Although some benefits can be delivered simultaneously, this was not always the case. The floodwater storage and production scenarios delivered similar levels of ecosystem services, scoring highly on production and floodwater storage, at the expense of environmental indicators. Not surprisingly, the agri-environment and biodiversity scenarios generally had a positive environmental impact. However, the biodiversity scenario resulted in increased flood risk for settlement and transport, and reduced floodwater storage as the existing flood banks would be breached. Under the agri-environment scenario, as flooding is controlled with sluices and pumps, there was little increase in flood risk and the floodplain can be used for floodwater storage.

This floodplain example illustrates how a careful combination of scenarios and indicators, set in an ecosystem services framework, can help to assess options for management of multiple services.

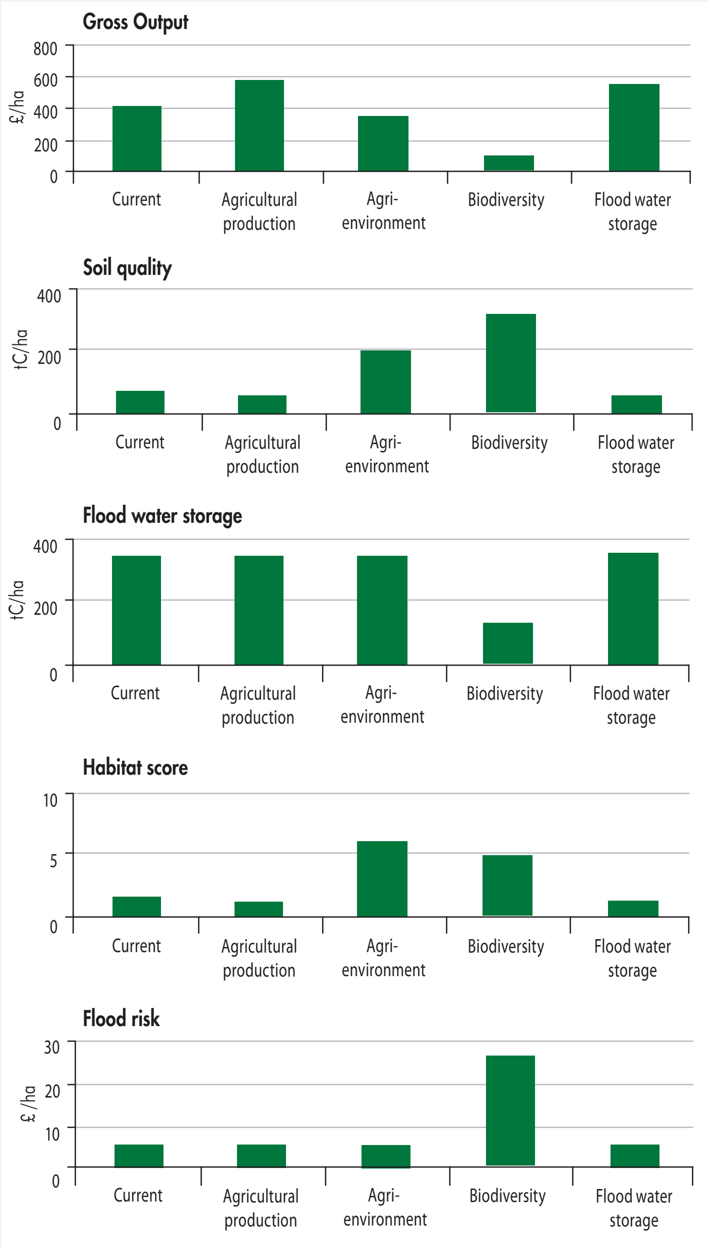

Figure 3 Relative levels of selected ecosystem services under five alternative scenarios. Source: data from Posthumus *et al.* (2010). Copyright (2010), reproduced with permission from Elsevier.

be outweighed by enhanced biodiversity and opportunities for game shooting. Similarly, many semi-natural habitats, such as upland heaths and species-rich grasslands, require extensive grazing for their persistence, and the grazing animals provide meat that can be sold at a premium.

This approach can be taken a step further by allocating land to different combinations of ecosystem services according to topography and soil type, both at the farm and at larger, catchment or landscape scales. For example, grass field margins can reduce the transport of soil and nutrients to water, and provide habitat for pollinating insects, predators of crop pests and nesting birds (Stoate *et al.* 2009). Constructed wetlands can reduce the transport of sediment and nutrients from field drains and ditches to watercourses, while also providing benefits to terrestrial and aquatic biodiversity within the farmland ecosystem (Stoate *et al.* 2006). Species-rich legume grassland supports higher insect abundance and richness, including pollinating species, and provides greater carbon sequestration potential than monocultural grassland (De Deyn *et al.* 2008). Such changes would result in landscapes that are more diverse but less familiar, with impacts on cultural services varying from place to place (Firbank 2005).

7.6 Future Research and Monitoring Gaps

The sustainable management of Enclosed Farmland involves the long-term co-delivery of agricultural production and other ecosystem services by land managers in response to the potential of the land (climate, soils, topography) and economic, policy and societal drivers. The major driver is likely to be the projected rise in human population causing increases in global demands on ecosystem services from farmland over the coming decades (Tilman *et al.* 2002; MA 2005). There is an expectation that food production will have to increase by as much as 50%, alongside increases in fuels and biomaterials. Agricultural production in the UK is likely to be affected less by climate change than in many other parts of the world, implying that an even greater increase in food output will be required here. This also implies that the market and policy situation may well change more rapidly than the research base. There are major knowledge gaps at all levels regarding the supply of ecosystem services from Enclosed Farmland.

7.6.1 Enhancing the Provision of Multiple Ecosystem Services

Research is needed into the development of more productive, resilient, multifunctional agro-ecosystems. The challenge is that these properties are not necessarily synergistic.

Increased food production must be supported by research that stresses increasing productivity within traditional agricultural areas, such as breeding, crop protection and animal disease management, using new technologies including genetic modification, genomics, metabolomics, etc. (Royal Society 2009).

There is a great need to optimise the efficiency of nutrient use across the food chain in order to reduce releases of nitrogen compounds and phosphates to air and water, to cope with potential increasing costs of artificial fertiliser and shortages of phosphorus, and to minimise the competition for protein from arable crops between human and livestock consumption. Some of this work will involve further developments in precision agriculture and storage of manures; some will address nutrient management at the farming system and catchment scales. Research is needed into how to balance the efficient use of food processing wastes with food safety. There may be scope to manipulate biogeochemical processes directly by manipulating soil biota once their role is better understood; the broader question of the importance of biodiversity in underpinning stability of ecosystem service provision, including agricultural production, remains under-researched (Loreau 2010).

Farming systems in the UK have proved extremely resilient to date, not least due to the mild climate, good soils and a highly adaptive farming industry. But, as ever, the industry faces multiple pressures. Social pressures include changes to the farming community itself, competing pressures on the land, access to new technologies, and the changing attitudes of food consumers and users of Enclosed Farmland for leisure, exercise and culture. Economic pressures include fluctuating financial returns to the farming community, the rapidly evolving policy requirements, and a potential decline in the availability of phosphorus for fertiliser. Climate change poses major challenges to food production. It may be possible to design farming systems that are resilient to climate change, for example, protecting livestock from heat stress in controlled buildings or using greater woodland cover in grasslands to provide cooler microclimates. A substantial increase in the price of fossil fuels could generate an important tipping point, forcing farming systems to optimise or replace tractors, road transport and inorganic fertilisers. It is not clear what low-carbon agriculture would look like.

The co-production of multiple ecosystem services in multifunctional agricultural landscapes remains under-researched. Clearly, a better understanding of management of ecosystem services, and how they interact, is critical (Bennett *et al.* 2009). We lack sound evidence of the relationships between provisioning and regulating services; instead, we tend to rely on proxy data, such as numbers of pollinators. This is because the critical experiments are often difficult and expensive to make at appropriate scales. Existing quantitative data are not amenable to complex optimisation modelling at farm, landscape and catchment scales. New experiments are needed at scales from controlled environment to catchment, combining different forms of land management; this should be supplemented by systems modelling because the actual outcomes of different land management combinations on multiple services are likely to be sensitive to soils, location and weather patterns. Long-term monitoring over multiple scales of space and time is needed to validate and refine the models (Bennett *et al.* 2009; Carpenter *et al.* 2009).

7.6.2 The Governance of Delivery of Ecosystem Services

The governance of ecosystem service delivery is currently highly complex and not well adapted to the cost-effective delivery of ecosystem services from Enclosed Farmland. At the moment, delivery is sensitive to volatile commodity markets, government support and regulation. In principle, ecosystem benefits and disbenefits could be considered in terms of value to society, and so could be costed and funded through agri-environment schemes or other mechanisms. Unfortunately, the values of such benefits are changing rapidly (e.g. the recent rise in importance of greenhouse gas mitigation) and are perceived very differently by different members of society. For instance, how does the public trade off food supply, local produce, prices of food and biodiversity in the UK countryside and abroad? Differences in responses to such questions help drive the diversity of agricultural production methods, from smallholdings right through to large-scale suppliers of commodity crops.

It is difficult to value long-term needs as opposed to short-term gains (Bennett *et al.* 2009); currently, most land managers are only rewarded for short-term success (MA 2005). Also, agricultural land use is fundamentally controlled by the market and the priorities of individual landowners and land managers, and so, even if the research base were strong enough to suggest optimum ways of producing multiple ecosystem services at landscape, catchment and larger scales, there is no clear governance mechanism for delivering such wider-scale benefits without compromising the benefits of farm-scale innovation and diversity.

7.6.3 Cultural Barriers to Implementation of Solutions and Knowledge Transfer

A third barrier is knowledge exchange. There needs to be greater dissemination of best practice; as noted above, take-up of precision arable farming remains low despite its benefits in terms of more efficient use of inputs. Knowledge exchange is needed to address conflicts between production and environmental knowledge cultures (Tsouvalis *et al.* 2000; Ingram 2008), and to enable the introduction of new skills in ecosystem management to profitable rural enterprises. There is also a need for much broader public engagement in order to better establish priorities, values and mechanisms for the delivery of ecosystem services from Enclosed Farmland, not least as the full cost for these services may prove far greater than allowed for in current policies and markets.

7.7 Conclusion

To conclude, Enclosed Farmland has been, and remains, a vital habitat in the UK in terms of food production and the provision of landscape and other cultural benefits. Yet it also imposes disadvantages to the UK in terms of greenhouse gas emissions, diffuse water pollution and losses to biodiversity. Greater demand is expected of multiple ecosystem services including food, bioenergy, greenhouse gas mitigation and cultural services, some of which can be delivered using current knowledge, while others could be met by novel approaches including spatial optimisation of land management. But there are major challenges and knowledge gaps regarding how such integrated land use could be determined and delivered given that the drivers of decision-making (e.g. marked changes in weather, changes in the price of carbon, the desire for biodiversity conservation, the need for pest control, nutrient cycling and the control of diffuse pollution, etc.) are becoming more complex, and cross scales and ownership boundaries; that relationships between regulating services and food production are not clear; and that the values of different ecosystem services are not well defined.

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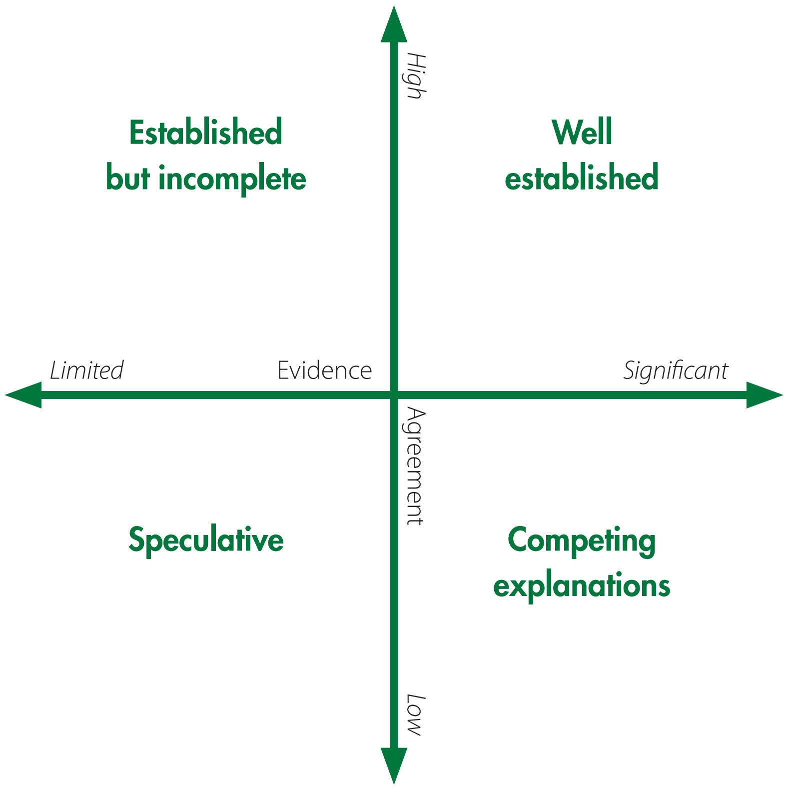
Appendix 7.1 Approach Used to Assign Certainty Terms to Chapter Key Findings

This chapter began with a set of Key Findings. Adopting the approach and terminology used by the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Assessment (MA), these Key Findings also include an indication of the level of scientific certainty. The 'uncertainty approach' of the UK NEA consists of a set of qualitative uncertainty terms derived from a 4-box model and complemented, where possible, with a likelihood scale (see below). Estimates of certainty are derived from the collective judgement of authors, observational evidence, modelling results and/or theory examined for this assessment.

Throughout the Key Findings presented at the start of this chapter, superscript numbers and letters indicate the estimated level of certainty for a particular key finding:

1. *Well established:* high agreement based on significant evidence
2. *Established but incomplete evidence:* high agreement based on limited evidence
3. *Competing explanations:* low agreement, albeit with significant evidence
4. *Speculative:* low agreement based on limited evidence



a. *Virtually certain:* >99% probability of occurrence
b. *Very likely:* >90% probability
c. *Likely:* >66% probability
d. *About as likely as not:* >33–66% probability
e. *Unlikely:* <33% probability
f. *Very unlikely:* <10% probability
g. *Exceptionally unlikely:* <1% probability

Certainty terms 1 to 4 constitute the 4-box model, while a to g constitute the likelihood scale.